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GRADY TRIPLETT
Editor

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MASONEILAN

VOLUME 19, No. 3 MARCH, 1940

REFINER
AND NATURAL GASOLINE MANUFACTURER
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The Look Box

UNTIL a line is drawn between control and conservation, there can be no honest appraisal of federal legislation and the petroleum industry. Conservation is frequently mentioned but control is apparently what is sought.

Conservation or Just Control?

Another plea of government witnesses is the necessity of oil for military purposes.

On the score of conservation the oil industry can point to more progress than can government. Its leading contribution is cracking and related processes such as polymerization and alkylation. What has been accomplished in 20 years in refining technology should satisfy even the most rabid adherents of federal control.

Witnesses in behalf of the Cole bill mention waste in production. It is even mentioned in the draft of the legislation, evidently as justification for passage of the bill. The industry never has denied waste. What it does contend is that waste is being overcome and the record of government and industry indicates that the industry will overcome waste more rapidly than will government. The urge for profit is more successful than the urge for mere control.

As for mere control with the need for oil as a war necessity the opinion of experts does not give ground for fear. The war department has estimated possible increase of 15 percent in consumption in case of a major conflict. The oil industry is ready to take care of that and more. From the navy department testimony has been given that its demands might increase from 36,000,000 to 50,000,000 barrels in a year. Single oil fields can take care of such an increase and still be under restriction.

John W. Frey, associate director, Petroleum Conservation Division, Department of the Interior, said before the recent meeting of the American Institute of Mining and Metallurgical Engineers:

"The people who predict abundant petroleum reserves 50 or 100 years from now do not give bond for the accuracy of their statements."

Neither do men with the government give bond for their word that oil supplies will be exhausted within 50 or 100 years. No one in the oil industry knows how long the oil supply will last and no one in a federal bureau knows.

But why should the fact that no one knows how much oil will be available at the end of a century be reason for federal legislation? If the industry proves by its record to be more capable in conserving the oil reserve that is known, federal legislation can add nothing.

Somehow the impression persists that federal legislation is wanted simply for the sake of having control. By legislation the government once

had control of Teapot Dome, which either never harbored much oil or was poorly conserved.

Conservation can apply only to oil known to exist and the industry is progressively improving its technique over what it owns. Control assumes that no more oil fields will be found and that the known must be saved or it assumes that much more oil will be found and that only government can properly administer it.

It would be enlightening to have some addict of federal control outline the things he would do with an oil-bearing undrilled structure, private ownership, competitive selling and other hindrances being what they are. He could lock it up and keep it or develop it under the best known technique, which is what industry does. As for saving it, the federal government could buy one or more such structures without imposing control on the industry.

PETROLEUM refining holds first place in wage scale for unskilled workers, according to the United States Bureau of Labor Statistics. The bureau studied 20 industries and found refining well ahead.

High Wages Good Workers

It would be advantageous if some measure could be found for the ingenuity of workmen. If that could be determined, the effectiveness of refinery workers, skilled and unskilled, doubtless would rank at the top.

The petroleum industry is fortunate in the type of workmen it draws and in part the good fortune may be just good business, one part of which is high wages.

STATE-LINE barriers against the automobile had one rung removed by decision of the United States Supreme Court, which held unconstitutional the Arkansas statute which prohibited any vehicle from entering the state with more than 20 gallons of gasoline until the state tax of 6.5 cents a gallon had been paid.

One Rung Off A State Barrier

State laws are a serious hindrance to use of the automobile and the consumption of gasoline and it is heartening to know that at least in one particular barriers are being knocked down.

The Arkansas law was an instance of double taxation, for the truck owner must pay the state tax where his fuel is bought and would have been compelled to pay again on whatever amount his supply exceeded 20 gallons upon entering Arkansas.

ANOTHER interpretation that the recycling process justifies is that liquid recovery allows the process to continue. If natural gasoline or other liquid recoveries were not a part of reservoir pressure maintenance in the distillate fields as well as those of normal crude oil content, there would be no such program of recycling as has grown and continues to grow.

All Because of Liquid Recovery

In his paper before the American Institute of Mining and Metallurgical Engineers last month, E. O. Bennett, Continental Oil Company, gave a striking picture of pressure maintenance, especially as it involves cooperative effort. This one phase of oil-field practice is using 85,000 compressor horsepower to return 800,000,000,000 cubic feet of natural gas per year to formations. The amount of gas returned is equivalent to 35 percent of all natural gas consumed in the United States.

Of the cooperative venture for the K-M-A field Bennett said:

"This project is the largest cooperative development of this kind ever undertaken and shows definitely that, having been shown the way, producers and operators are quick to take advantage of modern technique without compulsion of regulatory bodies."

Somewhere in each process there is extraction of valuable liquid. Without this recovery, cost sheets would not be so attractive.

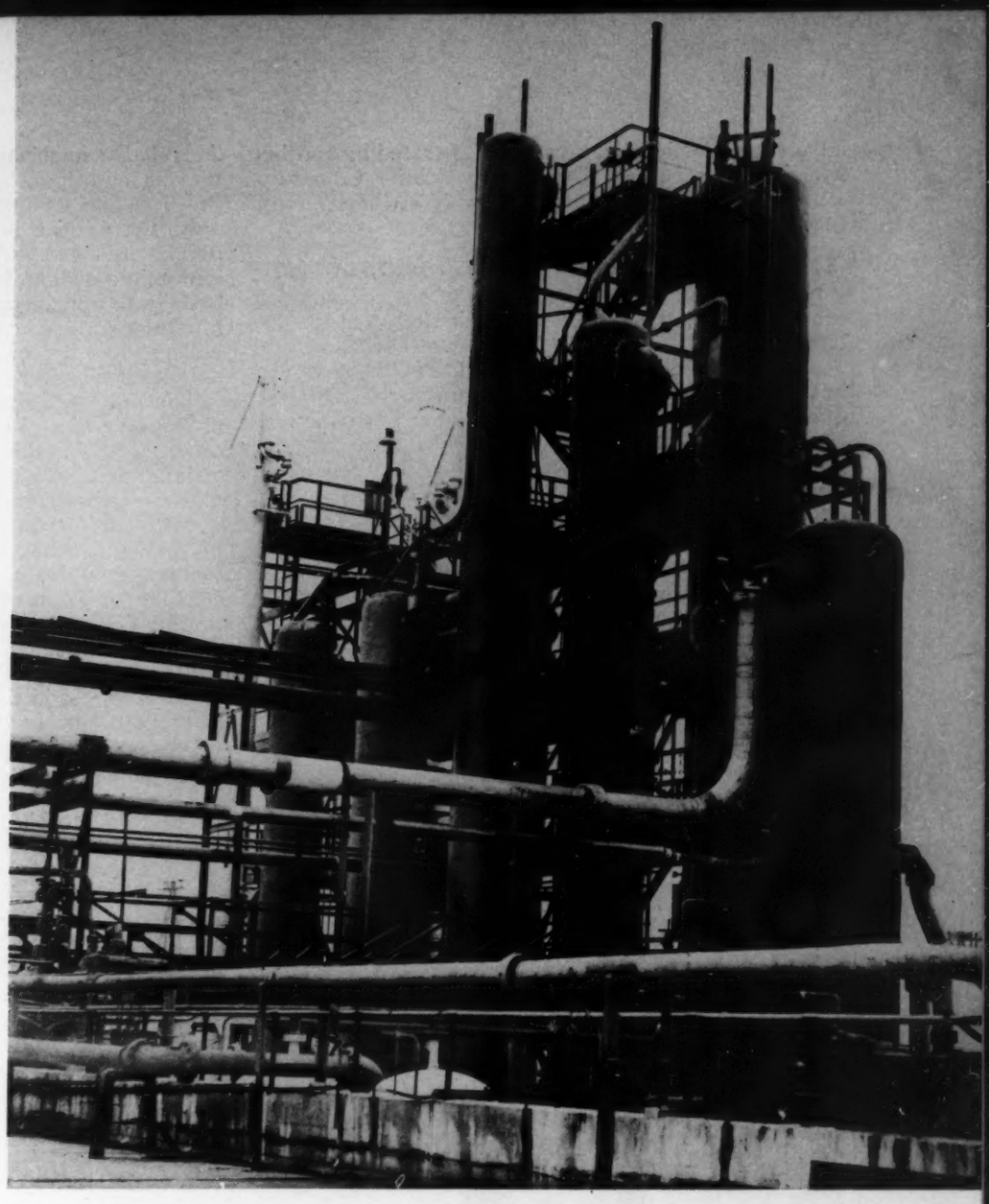
NOW that the technologists are considering revision and clarification of the methods by which octane numbers are determined, it is in order to question the use the industry makes of some of its technical knowledge.

Worn From Over Use

Technical methods change, often rapidly, often slowly. That they change is an indication of progress. Gravity was once a foremost test for gasoline but it had to go.

When the drive for better anti-knock performance became a factor in motor fuel, the word octane came into the literature. It finally came into random use by salesmen and copy writers. Few knew what it meant. They simply had something on which to base sales appeal.

It is not likely that octane rating will be abandoned as a specification for gasoline. It is likely that improvement will be made in determining the rating because there is confusion in technical circles.



Distillation section of coal hydrogenation plant at Billingham, England.

Continuous Coal Distillation *Similar to* Petroleum Refining Technique

B. ORCHARD LISLE

BRITAIN'S leading manufacturer of synthetic oil products from coal recently completed a new continuous-distillation plant which is the first of its kind to be based on the technique used in refining crude petroleum, as well as embodying the latest practice in coal-tar treatment.

Automatic as far as possible, now that it has been in operation several months the refinery of British Diesel Oil & Petrol Company, Ltd., can safely be said to be greatly superior to the intermittent plants which have been used in previous installations of the Low Temperature Carbonisation, Ltd., interests (the parent concern) and by their contemporaries.

Better fractionation and more efficient washing has improved the quality of the products. The distillation unit is of flexible design and operation, enabling it to meet varying demands, but the usual yield is about 10 percent motor fuel, 15 percent Diesel oil, 16 to 18 percent cresol, 59 to 61 percent creosote and fuel oil, and the remaining 20 percent pitch. In addition, the

adjacent coal carbonization plant, operated by another subsidiary of L.T.C., Derbyshire Coalite Company, Ltd., yields a substantial quantity of stripped motor fuel of good anti-knock rating.

EXTENT OF BRITISH COAL OIL PRODUCTION

Great Britain ranks third in the world consumption of petroleum, requiring approximately 11,430,000 barrels of gasoline, 1,280,000 barrels of Diesel oil, and 14,280,000 barrels of lubricating oil. Of this, however, only about 8 percent of total requirements are produced from indigenous sources; some from distillation of the hydrocarbon content of the Scottish shales, but most is from heat treatment of coal. Petroleum production is negligible, despite the several million dollars spent during the past five or six years in drilling operations all over the United Kingdom.

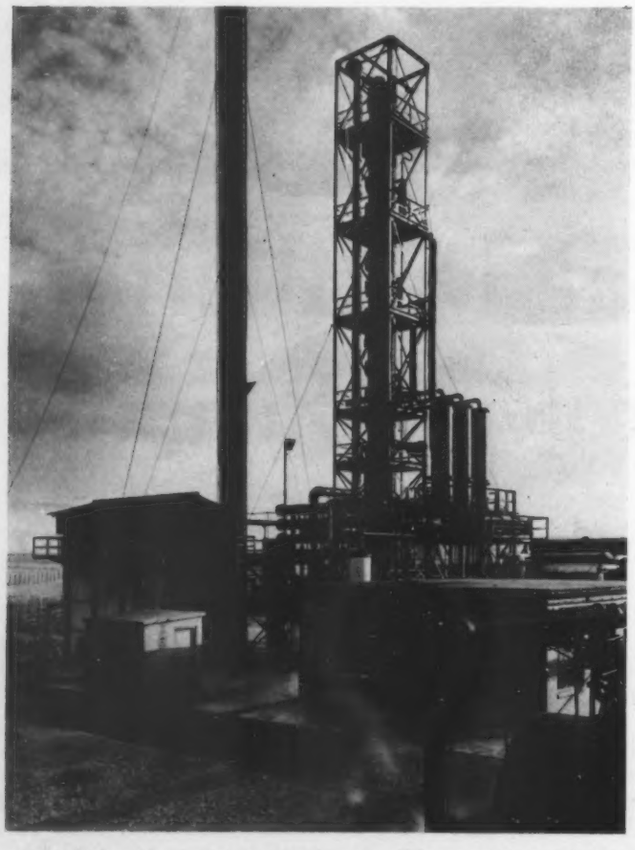
The recent report of the Falmouth committee has refuted the idea that Great Britain could or even should seek to make itself independent of imported petroleum supplies under existing conditions, but it is felt to be in the national interest to increase the proportion of consumption obtained from domestic sources.

GASOLINE PRODUCED FROM COAL IN BRITAIN (BARRELS)

Method	1938	1937
Low-Temperature Carbonization	37,200	28,600
High-Temperature Gas Works	....	285,700*
Coke Ovens	1,563,000	985,700*
Coal Tar Distillation	....	337,200
Hydrogenation (coal and coal tar)....	1,208,600	1,000,000
Total	2,808,800	2,637,200

* Benzol

Since the above annual figures were released last November there has been a marked improvement in the relative importance of low-temperature carbonization as additional plants have been erected during the first half of 1939. These figures are for gasoline only, for despite the extensive research carried out by private firms and government bureaus it has been impossible to obtain a lubricating oil from coal by hydrogenation or any other method, although both low-temperature carbonization and hydrogenation will produce a fuel which may be used satisfactorily as Diesel oil after doping with an anti-knock agent.



Main distillation unit, showing pipe still and fractionating columns, at Bolsover coal refinery.

The only hydrogenation plant in England is that of Imperial Chemical Industries, Ltd., at Billingham-on-Tees, using the Bergius patent. In this process, ground coal is washed to an ash content of 2 percent and mixed with heavy oil (usually creosote or low-temperature crude) as a carrier; a greater proportion of the liquid than solid has been found most satisfactory for operation. The mix is subjected to hydrogenation at a temperature of about 450° C. and at pressures between 275 and 350 atmospheres, converting it almost entirely to liquid products. After distilling off the gasoline produced, the lighter products require little additional treatment, while the residue is recycled for further hydrogenation. The gasoline produced has an octane rating of about 75 and may be readily doped to aviation specifications.

There are 13 low-temperature carbonization plants in England to the one hydrogenation, and any increases in oil output from coal may be expected from the former rather than the latter due to the high overheads involved. The carbonization plants have an average yield of about 3.5 U. S. gallons per ton of coal processed, and vary somewhat in nature: rotary and stationary retorts, some heated internally and others externally, mostly intermittent in operation. By far the most satisfactory of the processes extant has been that of Low Temperature Carbonisation, Ltd., which is the only one of these concerns known to have established itself upon a sound commercial footing.

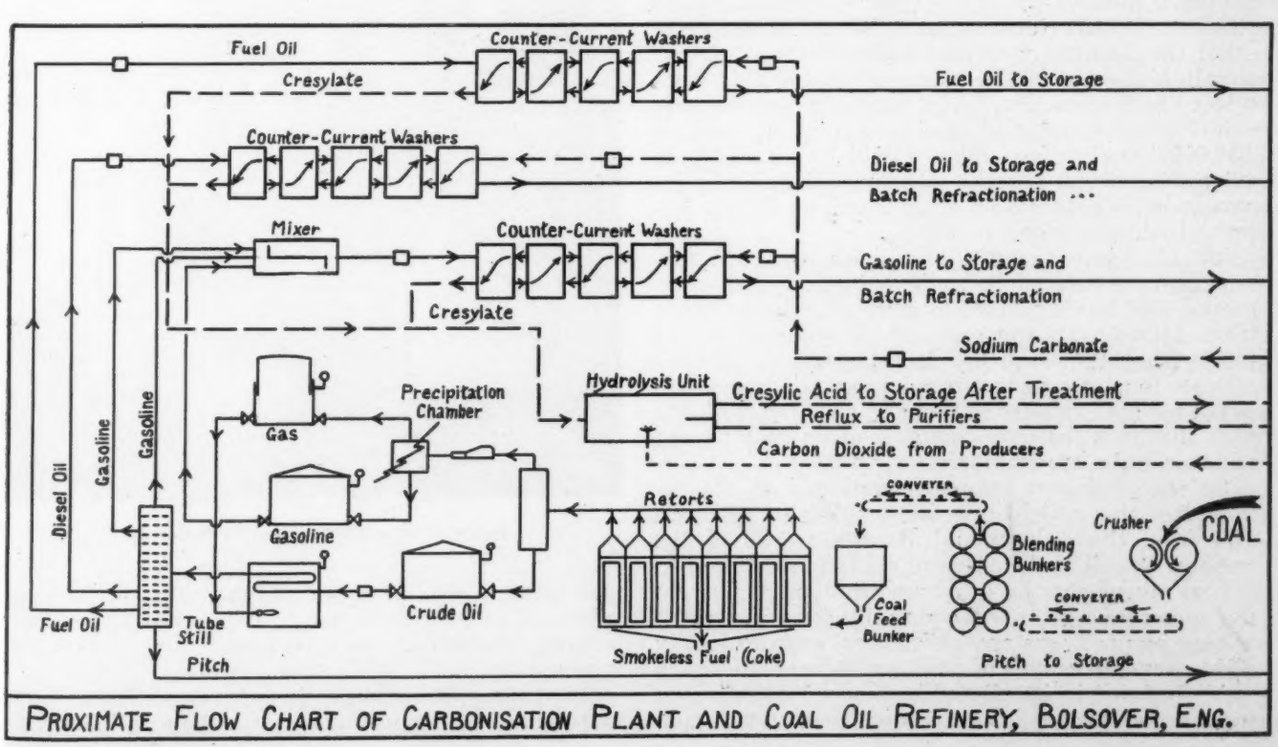
COLONEL BRISTOW'S ENTERPRISE

A little more than a decade ago Low Temperature Carbonisation, Ltd., was just one of several small companies that had a pretty good process which could produce a liquid fuel that further refining could make satisfactory for use as a gasoline substitute—but, like its contemporaries, it was virtually on the rocks as a financial proposition. Colonel Whiston A. Bristow, a consulting engineer who turned out to have a good head for business as well as for the technical aspects, was asked to take over the management of the company in 1927. After two or three years he had become so interested in the possibilities of this infant industry that he gave up entirely his private practice and devoted all his time to developing the Coalite process.

From the very start, Bristow realized where his predecessors had made their greatest error—they had been seeking a coal which would give the greatest yield of oil per ton, but had ignored the other aspects. The result was that they had as residue a coke which had no sales value and therefore could not be disposed of, while the price realized for their products (even with a preference by tax exemption, now at 12.2 cents per U. S. gallon) was not adequate for economical operation.

He saw that under existing conditions it would not be possible to make a profit on the basis of gasoline output alone, and based his entire procedure on the production of a smokeless fuel which was superior to ordinary coke and would find a ready market for

Britain's largest unit for production of gasoline from coal is the hydrogenation plant at Billingham, England. Even with a large tax preference, economics preclude its duplication.



PROXIMATE FLOW CHART OF CARBONISATION PLANT AND COAL OIL REFINERY, BOLSOVER, ENG.

Acid rerunning stills at the Bolsover refinery.

household use. As by-products of the process he obtained appreciable quantities of gasoline of good quality as well as several valuable chemical products.

Bristow has never over-stated his claims and agrees that it is doubtful that England will ever make enough oil through his or any other process to render petroleum imports unnecessary. What he does say is that the country consumes 40,000,000 tons of coal annually for domestic heating and that if this were replaced with smokeless fuel it would be necessary to raise 50,000,000 tons of coal and that a yield of 4,286,000 barrels of gasoline would be obtained, as well as 25,716,000 barrels of heavy oil suitable for conversion to gasoline or other fractions by distillation or hydrogenation.

Since he introduced his policies the 32 low-temperature retorts, little trade and no oil distillation plant of 1937 has increased to more than 1000 Coalite retorts as well as a modern coal oil refinery. In this same period the company has treated more than 3,000,000 tons of coal and has developed an excellent market for both smokeless fuel and gasoline, with the result that it is the only company of its type paying dividends to its stockholders.

The new Bolsover refinery mentioned at the beginning of this article gets its supplies of raw material from the Askern and Barugh works of the company as well as the adjacent colliery. At Bolsover, the coal mined near-by is washed to about 3 percent ash, and conveyed to concrete bunkers from the washing plant. There are 16 of these, each 70 feet in height. Several seams of coal are mined and each type is isolated in its alloted bunker for blending to very precise proportion. Electrically-operated conveyors run from these bunkers, and the blend is obtained by adjusting the speed. Elevators and conveyors carry the final mixture to the retort-feed bunkers, situated above the eight batteries of retorts, which hold about 500 tons of coal—enough for 24 hours operation.

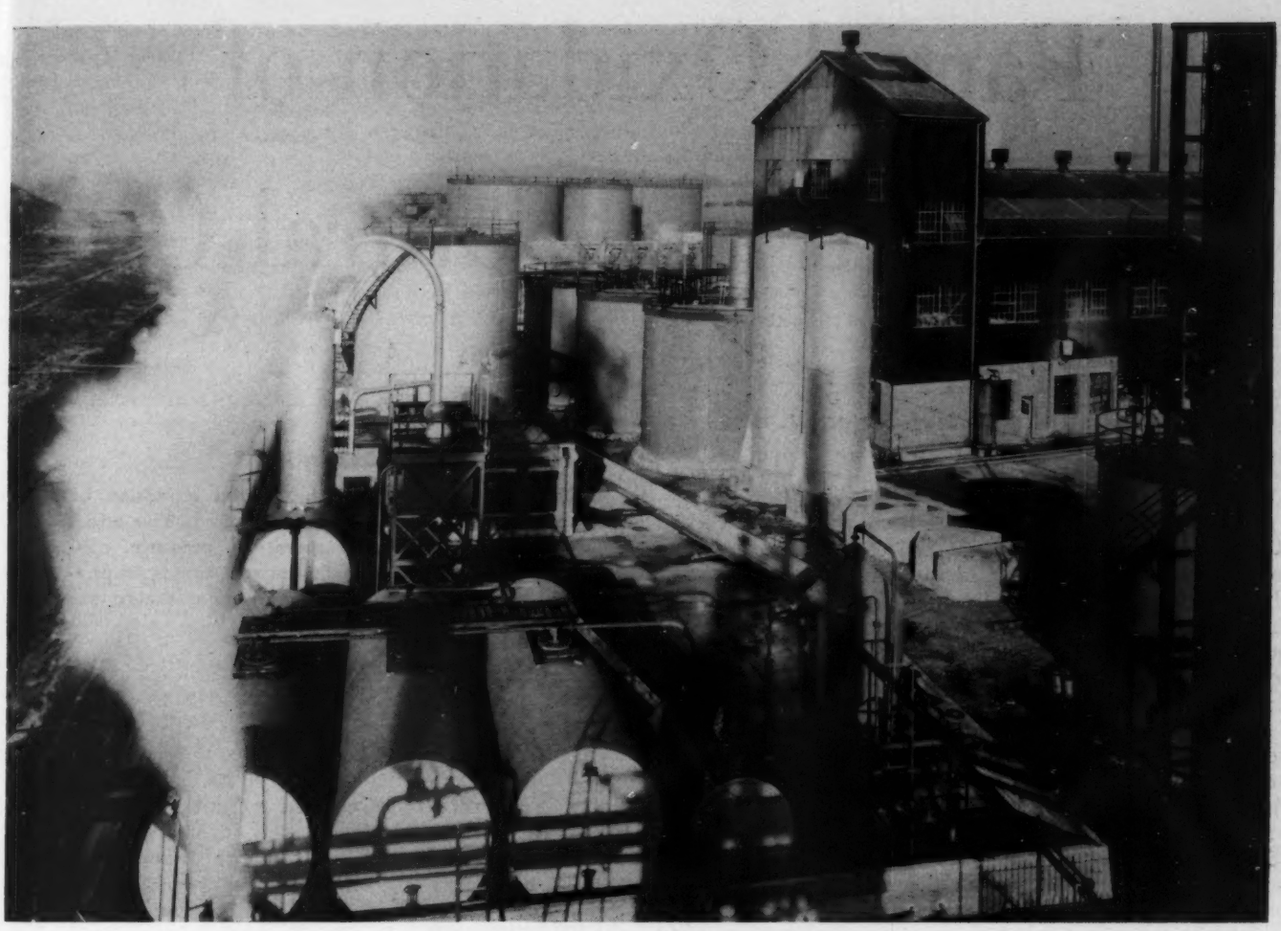
The uncondensed gas passes from the retorts to electro-static precipitation chambers where a static discharge of 80,000 volts removes all suspended matter, while the condensed crude oil passes to storage. Gasoline is stripped from the gas, which is then returned to gas-holders for use as plant fuel. There is a good local demand for the ammonia which may be extracted from the sulphate.

The crude refinery stock produced by the retorts is neither a petroleum nor a tar, as the chemical characteristics of low-temperature coal oil differ considerably from both. The crude contains large quantities of phenols and is rich in olefins, but has a low sulphur content. A substantial part of the plant is devoted to the removal of these phenolic bodies, or tar acids. After they have been removed, the neutral or washed oils are the basis of both motor and Diesel fuel, the former being increased in volume by addition of spirit stripped from the gas from the carbonization plants.

Although the company has limited the release of information with regard to the process, it is possible to give a general outline of the flow. Crude stock is passed through a tube still which takes off an overhead, three side streams and a pitch as bottoms. This unit is very similar to the conventional petroleum tube still fitted with external strippers and the usual heating installation with radiation and convection banks.

Interior of washing plant at Bolsover.

The tube still, incidentally, is quite different from petroleum practice in that it is for the most part con-



Gasoline refining plant at the coal oil refinery of Low Temperature Carbonisation, Ltd., at Bolsover, England.

structed of stainless steel, while cast iron replaces mild steel on other portions of the equipment. The nature of the crude presents a corrosion problem which would have been very serious had normal materials been used.

From the tube still both the light and heavy fractions pass to a washing plant similar to the larger counter-current installations provided for the Trieste (Italy) petroleum refinery of Aquila S.A. and for the plant of Manchester Oil Refinery, Ltd., in England. The advantages of the system are even more marked when treating coal oil products than in petroleum refining; the treatment extracts the tar acids more efficiently than standard practice as well as reducing soda consumption. The latter diminishes the amount of sodium carbonate to be recausticized—a considerable economy, as that operation is fairly costly.

After treatment the light fractions are redistilled once more in a semi-continuous still of the batch type. Similar equipment is employed for rerunning the Diesel oil fraction to required specifications, the distillation columns being of a standardized design and to a certain extent interchangeable.

Washing with caustic soda removes the tar acids from the semi-refined oils by taking them into solution. This solution of tar acids, or cresylate, is subjected to a series of treatments after which hydrolysis by acidification of the cresylate, with CO_2 generated from coke in producers, throws the purified acids out of solution. These cresylic acids are given further treatment and transferred to storage, from which supplies are taken at intervals for refractionation in the distillation units. The various standard specifications of cresylic acid produced are almost without exception of 99-100 percent purity.

Caustic soda is produced by reaction of lumpy lime with sodium carbonate solution on a large scale, and ultimately there will be four 13,700-gallon (U. S.) capacity causticizers continuously at work. A rotary vacuum filter, settling tanks and filter presses are available for the separation of the solid calcium carbonate from the caustic soda produced, and the caustic soda is concentrated to the desired strength in a Kestner evaporator after it has been completely freed from solid matter.

The germicidal value of some of the tar acids is almost four times as great as that of standard products from other sources, owing to the temperature employed and the method of distillation.

Producer gas is employed for firing throughout the refinery, although equipment for burning oil is available should it be desirable to operate on that product. A line runs from the generating plant at the nearby carbonization works to the refinery for supply of steam.

Bolsover coal oil refinery is a success not only from the standpoint of combating the problem of corrosion, but the tube still has given a much finer degree of fractionation than is usual in tar-distilling practice, and the quality of the products is much superior to those obtained with the older intermittent equipment.

Partial Oxidation of Petroleum and Natural Gas

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ABSTRACT

THE present status of the partial oxidation of petroleum hydrocarbons is reviewed. The effect of the variables time, temperature, pressure, concentration, and catalysis on the reaction is emphasized. Problems involved in equipment design are also presented.

A NUMBER of papers have been written concerning the application of partial oxidation processes to petroleum hydrocarbons. Most of them have been so obscured with details of individual experiments that the important factors involved have not been evident. The purpose of this article is to present the known facts concerning these partial oxidation processes and to correlate this information into a usable entity.

Partial oxidation (controlled oxidation for the purpose of forming valuable intermediate products) is just one phase of the attempt to build up an auxiliary chemical industry within the petroleum and natural gas industries. An excellent beginning has been made by several major oil companies, either through subsidiaries or special departments within the company. Oxidation processes, however, have not been developed nearly so widely as some of the other chemical engineering unit processes such as pyrolysis, hydration and halogenation.

On the other hand, partial oxidation processes present economic advantages not shown by the others. In catalytic air oxidation of hydrocarbons, the only raw material needed besides petroleum is air, and the possible products of the reaction include nearly the entire range of organic chemicals containing the three elements, carbon, hydrogen, and oxygen. In this category are included all of the alcohols, aldehydes, and ketones as well as most organic acids and esters. The wide use of these compounds in the great solvent and plastic industries represents only a small percentage of their potential possibilities. Petroleum and natural gas could be the major sources of these materials through the utilization of the proper fractions. It is only reasonable to expect that in such a complex mixture as petroleum that certain fractions could be used to greater economic advantage as chemical raw materials than as minor constituents of a fuel.

THEORETICAL CONSIDERATIONS

The course of the addition of successive oxygen atoms to a hydrocarbon molecule may be shown as follows:

$$\underset{\text{hydrocarbon}}{CH_3CH_2\text{----}CH_2CH_3} \xrightarrow{O} CH_3CH_2 \text{ .... } \underset{\text{alcohol}}{CH_2CH_2OH} \xrightarrow{O}$$

$$\underset{\text{aldehyde}}{CH_3CH_2 \text{ ..... } CH_2CHO} + H_2O$$

$$\xrightarrow{O} \underset{\text{acid}}{CH_3CH_2 \text{ .... } CH_2COOH} + H_2O$$

$$\xrightarrow{O} CO_2 + H_2O$$

Unfortunately the mechanism of the reaction is not so simple as the equation indicates. Various mechanisms have been proposed, each of which predicts different intermediate products. Probably each theory is correct to a certain extent since the existence of most of the proposed intermediate products has been proved. It is not the purpose of this article to discuss these various mechanisms. It should be pointed out, however, that the reason for this divergence of opinion is the complex mixture of substances obtained upon oxidizing a single hydrocarbon. Starting with petroleum, itself a complex mixture, an even greater number of products are obtained. It is this complexity of product that has been the major bar to the successful commercial application of partial oxidation processes. This does not mean that these processes are doomed to commercial failure, but rather that proper control of such reaction has not been fully established.

The remainder of this article will be devoted to a discussion of those variables through which proper control may be attained. For the purpose of illustrating the discussion, typical results on the oxidation of hydrocarbons taken from the literature are presented in Table 1. Scrutiny of the table shows that in nearly all cases, complex mixtures of organic compounds are produced.

In most chemical processes, there are five important variables, i.e., time, temperature, pressure, concentration, and catalysis. In partial oxidation processes, the type of control necessary depends upon whether the reaction takes place in the liquid or vapor phase. The latter has received the most attention from research workers, and will be discussed first.

VAPOR-PHASE OXIDATION

Effect of temperature—Temperature is probably the most important variable affecting vapor-phase oxidation, in that it affects both the equilibrium and velocity of every possible reaction which may occur within the reacting system. It not only affects the possible oxidation reactions, but also the decompo-

sition and polymerization of the various intermediate products. Since oxidation is an exothermic reaction, an increase in temperature generally decreases the equilibrium degree of completion of the oxidation and increases the degree of pyrolysis of reactants, intermediates, and products. It is obvious, then, that as far as yield is concerned, the temperature should be as low as possible.

On the other hand, it is only at elevated temperatures that the reaction proceeds at measurable rates. Accordingly, each oxidation reaction proceeds to the greatest actual degree of completion at some optimum temperature.

It should be pointed out that in flow systems, equilibrium is rarely if ever attained. Proper procedure seems to be to obtain the optimum amount of desired product quickly, and then to cool the mixture rapidly before decomposition and complete oxidation can occur. From the table it may be seen that the optimum temperature is rarely below 400° C. (752° F.) at atmospheric pressure, even when catalysts are used to increase the rate of reaction.

An important complication in the control of the reaction at elevated temperatures is its exothermic character. An enormous amount of heat is evolved, and this is difficult to remove uniformly. An increase in temperature at just one point in the reactor means partial destruction of the desired intermediate product, and perhaps further evolution of heat. When a catalyst is used, high temperatures may cause it to sinter, thus destroying its activity.

Effect of time—Time is a variable dependent upon the temperature. At a given temperature, a shorter time than the optimum leads to low conversions due to insufficient reaction; a longer time results in further oxidation or decomposition of the product. In catalytic reactions this time is commonly reported as time of contact, or as space velocity.* In the oxidation of hydrocarbons time of contact is rarely more than 10 seconds, and often in the neighborhood of 0.3 second.

* Space velocity is expressed as volumes of gas measured at standard conditions passed per volume of catalyst per hour.

COMPARISON OF TIME

An interesting effect of time of contact is shown by comparing processes for the oxidation of methylcyclohexane and cyclohexane (see Table 1). All variables, except time of contact, are essentially identical, yet one process (time of contact, 0.25 seconds) yields glutaric acid, HOOC-CH_2-CH_2-CH_2-COOH, and the other (time of contact, 3.6 seconds) yields maleic acid, HOOC-CH=CH-COOH, as the chief product. Since these two cases are taken from the patent literature, a reasonable doubt may exist as to their dependability, but the general effect of time is known to be somewhat similar.

Effect of concentration—In vapor-phase reactions the concentration of gases with respect to the catalyst is measured by the space velocity. Another important concentration factor is the ratio of air or oxygen-containing gas to hydrocarbon. A limiting factor in the selection of this ratio is the range of inflammability of the gaseous mixture. Pentane and air, for example, form explosive mixtures between 1.4 and 8.0 percent pentane, and the use of such mixtures must be avoided. Accordingly, for the oxidation of pentane, molar air-hydrocarbon ratios should either be below 12 or above 70 under ordinary conditions. A slight change in these limits is possible at high temperatures or pressures, or when operating in the presence of inert gases. Data on these variations is available in Bulletin No. 279 of the U. S. Bureau of Mines.

Most investigators prefer to use very low molar air-hydrocarbon ratios, such as about 0.15, because of the comparative ease of temperature control at such low air concentrations. At these low ratios, the yields of partial oxidation products approach the theoretical. The conversions per pass are naturally low, usually resulting in uneconomical processes. Under these conditions, oxygen may sometimes be used instead of air without materially increasing the explosion hazard. Even so, great caution should be exercised. Inspection of Table 1 will reveal the differences existing in this regard.

In certain cases, however, such as the oxidation of olefins to maleic acid, very high air-hydrocarbon

TABLE 1

Partial Oxidation of Hydrocarbons

HYDROCARBON	Temp. Range, ° C.	Pressure (Atmospheres)	Concentration: A. Molar Air-Hydrocarbon Ratio; B. Molar Oxygen Hydrocarbon Ratio	Catalyst	Products	Reference
Methane	350–400	25–150	B. 0.11	.....	Methanol, formaldehyde	14
Ethane	300–400	15–150	B. 0.10	.....	Methyl and ethyl alcohols, formaldehyde, acetaldehyde, formic and acetic acids	15
Propane	280–350	130–200	B. 0.08	.....	Me, Et, Pr, Bu alcohols, formaldehyde, acetaldehyde, acetone, formic and acetic acids	19
Propane	350	50	B. 0.06	diethyl-ether	Methanol, formaldehyde, acetaldehyde, higher alcs., alds, acids, ketones	2
Butane	380	23	A. 0.10 $\frac{\text{inert gas}}{\text{butane}} = \frac{140}{1}$	.....	Alcohols, aldehydes, acids, ketones, esters	1
Butane	280	140	B. 0.06	.....	Alcohols, acids, aldehydes	19
Pentane	240	135	B. 0.06	.....	Alcohols, acetaldehyde, acetic acid, acetone	19
White distillate (containing naphthenes). B.P. range 34-350° C.	380–410	1	B. 150-700	V_2O_5	**Maleic acid,** other acids, aldehydes	11
Kerosene	400–470	1	A. 13.0 $\frac{\text{steam}}{\text{kerosene}} = \frac{3}{1}$ by wht.	V_2O_5	Acids, aldehydes, ketones	9
Fuel Oil B.P. 200-300° C.	400	20	Air bubbled through oil	.....	Alcohols, acids, aldehydes, ketones, esters	16
Paraffin wax, m.p. 122-124° F.	120–180	15–40	Air bubbled through liquid	Mn oleate	**Monobasic and dibasic acids,** hydroxy acids, ketones, alcohols, esters, lactones	3
Ethylene	410–505	1	B. 0.11	.....	**Ethylene oxide,** aldehydes, acids	10
Ethylene	200	50	A. 0.50	.....	Acids and alcohols	17
Butene	250–400	1	A. 100	V_2O_5 and similar oxides	**Maleic acid,** (probably aldehydes and other acids)	18
Pentene, heptene, octene	350–500	1	A. 200-4000	V_2O_5	**Maleic acid,** other acids, aldehydes	4
Methyl cyclohexane	480	1	A. 100	V_2O_5	**Glutaric acid,** (probably other intermediates)	13
Cyclohexane	350	1	A. 50	V_2O_5 etc.	**Maleic acid,** other acids, aldehydes	12

Note: Major products in black.

ratios are preferable, since the excess air acts as a carrier to remove heat from the reaction chamber. These high ratios are possible because of the resistance of maleic acid to further oxidation, whereas simpler alcohols, aldehydes, etc., are not resistant.

Another factor involved in concentration control is the addition of inert gases to the system. Such gases as nitrogen, carbon dioxide and steam have been added in an attempt to reduce the rate of reaction, and to serve as a carrier for the heat evolved. The value of such addition in improving the yields of valuable products has not yet been demonstrated. Two cases are listed in Table 1, in which inert gases were employed.

Effect of pressure — In the oxidation of the lower hydrocarbons, pressure ranging from 15 to 200 atmospheres (220-3000 pounds per square inch) have been employed to increase the reaction rate and lower the temperature necessary for reaction. Oxidation under such pressures produce a greater proportion of alcohols and aldehydes than those carried out at atmospheric pressure. In fact, atmospheric oxidations are very difficult to stop at any intermediate point, except in those special cases where products highly resistant to further oxidation are formed.

Despite the fact that the use of high pressures means increased equipment costs and adds the hazard of a high pressure explosion, many investigators believe that the bulk of commercially successful processes will be carried out under these conditions.

Effect of catalysis—Because of the unfavorable conditions imposed on oxidation reactions by high temperatures, the use of catalysts to reduce the temperature necessary for adequate reaction rate is inevitable. In certain other unit processes, such as hydrogenation, the value of specific catalysts has been developed to a high degree. Unfortunately, though, our knowledge concerning oxidation catalysts is meager. It is not possible to predict from theoretical considerations what substance or mixture of substances will be a satisfactory catalyst for a given reaction. Accordingly the search for catalysts is essentially a trial-and-error procedure.

OXIDATION CATALYSTS

There is some evidence that successful oxidation catalysts should be oxides or salts of elements capable of existing in more than one form, such as V_2O_5 and V_2O_4. This has led to the statement that the oxides of the elements in groups IV, V, and VI of the periodic table are the chief oxidation catalysts. Insofar as the patent literature is concerned those most frequently mentioned are the oxides of vanadium, molybdenum, tungsten, manganese and chromium. Even these appear to be of limited value in certain cases. In 6 of the first 7 examples shown in Table 1 catalysts were of doubtful, if any, value. In those cases where the reaction temperature was lowered by the presence of an extended surface, it was believed that the specific composition of the surface was not important. On the other hand, there is no doubt that in those cases in which maleic acid was produced that the specific catalyst was very significant.

The search for catalysts is further complicated by the action of mixtures of oxides, which are often superior catalytically to the individual oxides from which they are made. The technical literature abounds in references to such mixtures, but at present they defy classification.

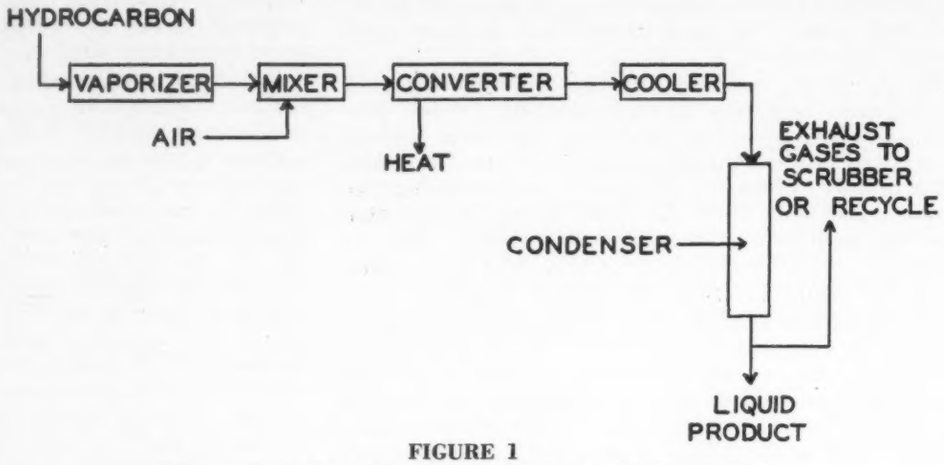

FIGURE 1
Diagrammatic flow sheet of hydrocarbon oxidation process

Still another important consideration is the catalyst support which may be chosen from among such materials as pumice, asbestos, metal turnings, kieselguhr, alumina, clay, and like substances. It has been shown that in many cases, supports having high thermal conductivity are the most satisfactory.[5, 6] The particular support chosen also has some effect on catalyst life, an important economic factor.

Besides solid catalysts, gaseous catalysts, such as nitrogen oxides[8] have also been studied. One case is shown in the table in which diethylether was used as a catalyst.[2]

LIQUID-PHASE OXIDATION

When the hydrocarbon to be oxidized is in the liquid phase, the effect of the several variables is considerably different from those already discussed.

At atmospheric pressure, the limiting temperature is the boiling point. This variable is closely related to the concentration since the solubility of air or oxygen in the hydrocarbon may be the controlling factor in the entire process. The solubility may be increased by pressure, but great care should be taken in liquid-phase pressure oxidations. Under these conditions, peroxide formation is imminent and the rapid decomposition of comparatively low local concentrations may result in a terrific explosion. The danger may be minimized by carrying out the reaction in tubes of small diameter.

Usually there is little relationship between satisfactory catalysts for vapor- and liquid-phase oxidations. Liquid-phase oxidation catalysts must either be soluble in the hydrocarbon medium or capable of staying in suspension easily. Taylor in the Chemical Engineer's Handbook mentions "resinates, stearates,

linoleates, oleates, borates, and phosphates of Mn, Fe, Ni, Co, and Cu."

EQUIPMENT DESIGN AND OPERATION

Catalytic vapor-phase oxidation equipment has 3 requisite parts:

(1) A means of vaporizing the hydrocarbon and mixing it with air.

(2) A reaction chamber, having a means of heating the reactants, removing excess heat from the reaction zone, and maintaining the temperature at an elevated level.

(3) A means of cooling the exhaust gases, and separating the product from these gases.

A typical flowsheet is shown in Figure 1.

Vaporization and mixing—Equipment for carrying out these two operations is standard and its design presents no particular difficulties. In operation it is imperative that an explosive mixture be not present at any time during the mixing. Hydrocarbons which are liquids at ordinary temperatures may be atomized and sprayed into preheated air or vaporized separately and then mixed in the proper proportion with air. One company prefers to vaporize light hydrocarbons like butane by bubbling nitrogen through a tank of the hydrocarbon and subsequently mixing it with the necessary air. In mixing the two gases, the mixing tube should be so designed that a maximum of turbulence can be acquired quickly. Such practice minimizes the danger of explosion.

In pressure oxidations, where the hydrocarbon probably remains in the liquid phase, the hydrocarbon should not be saturated with oxygen until the required temperature and pressure has been attained. The heating of such mixtures is extremely hazardous.

Convertors for vapor-phase oxidation—Convertor design is the most difficult problem concerned with partial oxidation equipment. A well-designed convertor must be such that large quantities of heat may be removed from the reaction zone constantly, while a uniform temperature is maintained throughout the zone. Further, the material of construction must not introduce any element that will catalyze undesirable reactions, or be attacked by the reacting gases. In a semi-works study of the pressure oxidation of pentane reported by Wiezevich and Frolich[19] (see Table 1) the authors found that considerable trouble was experienced with corrosion. Ordinary steel would not give a month's continuous service. Of the materials used, high Cr-Ni steels were most satisfactory, although Everdur, monel metal, and copper also gave good service. Particular difficulty was experienced in the high-pressure condensers.

HEAT REMOVAL

In practical convertor design, the corrosion problem, as great as it is, is overshadowed by the difficulties encountered in removing excess heat. In cases where a catalyst is used and the heat evolution is large, even greater care must be taken in order to prevent sintering of the catalyst. Contemporary practice places the catalyst in square tubes of such cross-sectional area that heat may easily be conducted from the catalyst to the tube wall, and yet not so small as to cause inordinately high pressure drop through the tubes. A circulating fluid surrounding the tubes removes the heat from the tube wall.

One of the most satisfactory designs from the standpoint of temperature control is incorporated in the Downs convertor for oxidizing naphthalene to phthalic anhydride (Figure 2). The heat-removing liquid is boiling mercury which can remove rather large quantities of heat as latent heat of vaporization. The mercury vapors are then condensed in a water condenser and returned to the system. The boiling point of the mercury is controlled by varying the pressure to which it is subjected. The chief objections to its use are the high specific gravity and low heat capacity of the liquid, and the toxicity of the vapor. As substitutes, various other boiling liquids have been suggested, including sulfur, diphenyl, naphthalene, lead, and various alloys.

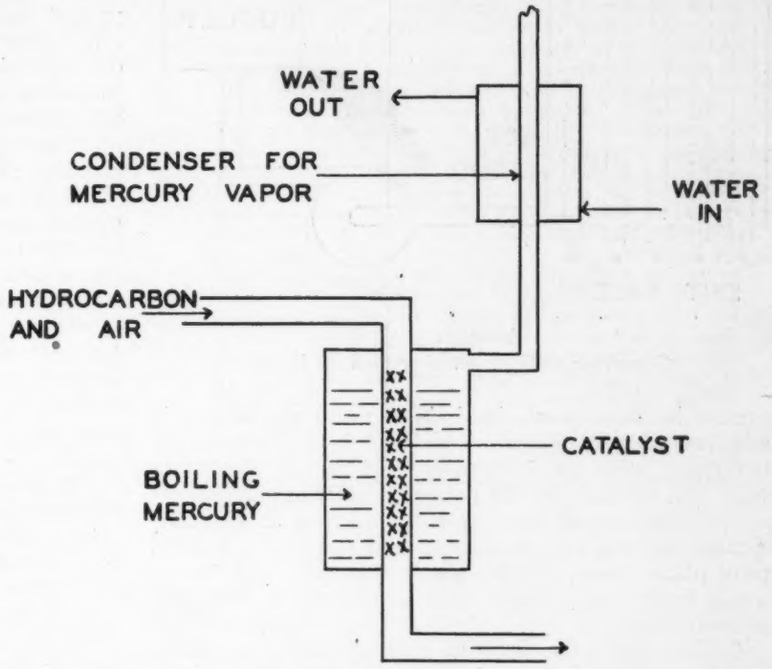

FIGURE 2
Diagram of single tube in Downs convertor

Other designers use circulating non-boiling liquids such as fused salts and high-boiling metals. One such design is shown in Figure 3.

It is possible to modify the foregoing designs considerably if low air-hydrocarbon ratios are employed. These processes result in only low conversions but the ease of removing the comparatively small amount of heat may create an economic advantage. Processes of this type may make use of a series of convertors between which small amounts of air are added to the hydrocarbon vapors. In this manner, only a little heat is liberated in each convertor. The James process for the oxidation of fuel oil makes use of this latter method (see Table 1).

In pressure oxidations, where the hydrocarbon remains in the liquid phase, the problem of heat removal is not so difficult. The amount of oxygen necessary to saturate the hydrocarbon between cycles

is so little that only a relatively small amount of heat is liberated.

A patent granted to Milas and Walsh[12] describes a convertor in which the hydrocarbon may be carried in the form of a mist into contact with the catalyst. It is claimed that in this process the heat of reaction vaporizes the hydrocarbon, and a temperature in-

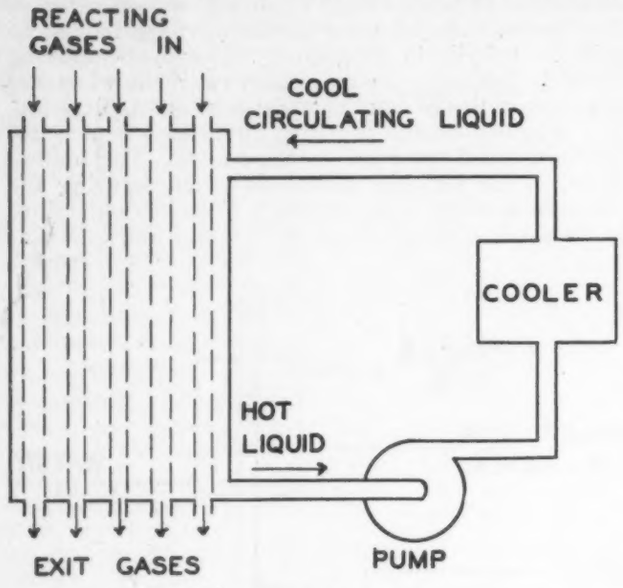

FIGURE 3
Convertor with circulating cooling liquid

crease is thereby avoided. The same apparatus is adapted to the oxidation of solid hydrocarbons by bringing finely divided solid particles into contact with the catalyst in the presence of oxygen.

The best actual convertor to be used in any particular process can be determined only by a careful pilot plant study. On this small scale, changes can be made easily and cheaply until a satisfactory design is accomplished.

Cooling and collecting—In most oxidation processes rapid cooling of the exhaust gases is necessary to prevent further oxidation and decomposition. Cooler and condenser design for such cases is fairly well standardized. The greatest difficulty is in selection of the proper material of construction, as was discussed previously.

Unreacted hydrocarbon and products which are not completely condensed may be recovered in a gas-scrubbing system of conventional design. In case one of the products is a solid at room temperature, it may sometimes be recovered in a comparatively pure state by sublimation in a chamber maintained just above the dew point of the exhaust gases.

After collection, the real difficulties begin. Separation of a complex mixture may be possible, but is usually uneconomical. Less costly means of separating and purifying the products of partial oxidation would change the economics of such processes overnight.

LIQUID-PHASE OXIDATION EQUIPMENT

Equipment for liquid-phase oxidation at atmospheric pressure is comparatively simple. In batch systems, the principal requisite is a container to hold the hydrocarbon-catalyst mixture, so arranged that air or oxygen may be brought into intimate contact with the liquid. Bubbling devices or mixers may serve to give adequate agitation. If the process is conducted at elevated temperatures, a reflux condenser will be necessary to prevent hydrocarbon loss by vaporization. Provision also must be made to prevent the trapping of unreacted oxygen in the reactor space above the liquid where it could form explosive mixtures with the hydrocarbon vapors.

In flow systems, pressure is nearly always used to increase the solubility of oxygen in the hydrocarbon, and to keep the hydrocarbon in the liquid state at elevated temperatures. The reaction is always carried out in heavy tubes, and the products cooled before reducing the pressure. Upon expansion, the products are led to a gas-liquid separator, after which the gases go to a series of scrubbers.

TECHNICAL PROCESSES

Considering the difficulties which are inherent in partial oxidation processes, it is little wonder that only a few technical processes are in operation. Most of the major oil companies have carried on research in this field and a few of them have even developed the processes to the semi-works stage. Although some of these projects have been abandoned as uneconomical at present, others are being continued.

Of the processes being operated commercially few operating details are available. One major oil company is manufacturing carload lots of methanol and formaldehyde by the oxidation of natural gas. Operating conditions probably include pressure in the neighborhood of 250-350 pounds per square inch, elevated temperature, and a low oxygen-hydrocarbon ratio. Several metals and oxides including platinum are known to catalyze this reaction, but it is possible that the chemical nature of the surface is not nearly so important as time of contact.

Another commercial process is the oxidation of ethylene to ethylene oxide. Patent literature indicates that a catalyst consisting primarily of silver is used, that pressures up to 50 atmospheres, and temperatures ranging from 300° to 400° C. are employed.

In Europe, fatty acids capable of being converted to soaps are made by the oxidation of the heavier hydrocarbon fractions. Low-temperature liquid-phase processes are used both with and without catalysts. The products are converted into an inferior grade of soap.

Just what other partial oxidation processes will be added to these in the next few years cannot be predicted. It is certain that considerable research and semi-works investigation will be prerequisite to commercially successful processes.

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The Improvement in Octane Number and Lead Susceptibility Resulting from

Solutizer Sweetening

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THE effect of solutizer sweetening on the octane number and lead susceptibility has been determined for 31 gasolines varying in source and type. Since solutizer treatment removes the mercaptans from the gasoline, instead of converting them to other sulfur compounds, the lead susceptibility was universally improved and the unleaded octane number was increased for the majority of samples. In no case was the octane number of the sour gasoline, either leaded or unleaded, decreased by solutizer sweetening. The percentage saving in tetraethyl lead resulting from solutizer treatment is largely dependent on the mercaptan content of the sour gasoline, irrespective of type, i.e., cracked or straight run. For the gasolines examined, the tetraethyl lead saving ranged from 9 to 65 percent, compared with the untreated gasoline, with an overall average of 31 percent corresponding to an average mercaptan sulfur content of 0.060 percent by weight in the sour gasoline. When leading to an octane number 5 units higher than that of the sour gasoline, solutizer sweetening resulted in a lead saving (at 0.25c/cc) ranging from 0.3 to 25 cents per barrel, as compared with the untreated gasoline, with an overall average of 2.5 cents per barrel.

IT is well known that the presence of sulfur compounds in gasoline decreases the octane number and the lead susceptibility [2, 3, 4, 6, 7, 8, 10, 11, 12]. The magnitude of this effect is dependent not only on the quantity of sulfur compounds present, but also on the type. Polysulfides are among the worst in this respect, followed by disulfides and mercaptans, thioethers, and thiophenes. Conventional sweetening processes convert mercaptans to disulfides, and in many cases, small amounts of polysulfides are formed as well. As a result of sweetening, the octane number and lead susceptibility are lowered to a greater or lesser extent, as compared to the sour gasoline, depending on the particular gasoline, the sweetening process employed, and how carefully the sweetening procedure has been carried out [1, 12].

The solutizer process accomplishes sweetening of the gasoline by extracting the mercaptans completely, using a "solutized" caustic solution, i.e., one of

TABLE 1
Properties of Untreated (Sour) Gasolines

TYPE OF GASOLINE	Item No.	A.S.T.M. DISTILLATION, °F.					A.P.I. Gravity	Bromine No. (9)	SULPHUR, % WT.	
		I.B.P.	10%	50%	90%	F.B.P.			Total	Mercaptan (13)
Straight run	1	91	108	143	226	293	79.3	1.3	0.466	0.172
	2	119	163	225	314	383	68.2	1	0.192	0.073
	3	120	160	208	270	320	68.7	0.2	0.018	0.005
	4	104	159	237	318	370	64.9	2.2	0.033	0.006
	5	113	164	226	293	351	62.6	0.8	0.112	0.052
	6	119	166	216	271	307	64.9	0.4	0.090	0.042
	7	118	178	279	403	433	59.4	13	0.115	0.042
	8	119	156	194	234	261	64.5	...	0.064	0.020
Cracked	9	115	159	270	374	398	57.9	88	0.217	0.082
	10	98	162	270	354	385	59.3	61	0.164	0.058
	11	92	108	136	187	245	77.9	93	0.292	0.184
	12	92	131	239	339	378	62.5	83	0.282	0.111
	13	105	141	231	361	410	61.1	...	0.062	0.019
	14	189	219	242	278	309	54.7	89	0.83	0.089
	15	95	136	262	369	412	57.8	74	0.137	0.034
	16	147	203	289	374	415	51.3	62	0.352	0.046
	17	109	158	260	354	389	57.9	92	0.128	0.037
	18	112	159	249	344	402	59.3	100	0.067	0.019
	19	98	147	263	385	435	55.9	74	0.303	0.090
	20	107	163	283	380	406	57.4	72	0.084	0.021
	21	93	144	270	357	381	56.6	77	0.645	0.099
	22	95	132	270	374	398	60.1	82	0.305	0.117
	23	99	127	241	378	410	59.8	91	0.135	0.022
	24	97	146	266	364	396	57.1	70	0.239	0.042
	25	140	191	250	325	384	54.4	74	0.186	0.035
Blend of cracked and straight run	26	105	145	241	332	377	60.9	44	0.090	0.022
	27	103	148	249	343	385	59.6	31	0.186	0.056
	28	111	164	259	353	388	60.7	38	0.093	0.016
Catalytic polymer	29	79	98	200	406	414	75.8	116	0.47	0.193
	30	84	114	216	360	414	71.1	157	0.138	0.045
Reformed	31	116	178	274	350	396	52.7	43	0.130	0.059
Averages—Items 1— 8 incl.								...	0.136	0.046
Items 9—25 incl.								...	0.261	0.065
Items 1—31 incl.								...	0.214	0.060

TABLE 2
Effect of Solutizer Sweetening on Octane Number and Lead Susceptibility

TYPE OF GASOLINE	Item No.	Octane Number of Untreated (Sour) Gasoline, Motor Method				Increase in Octane Number (Motor Method) Resulting from Solutizer Sweetening			
		Unleaded	Plus 1 cc. TEL	Plus 2 cc. TEL	Plus 3 cc. TEL	Unleaded	Plus 1 cc. TEL	Plus 2 cc. TEL	Plus 3 cc. TEL
Straight run	1	65.0	70.5	73.5	75.5	2.0	3.2	4.2	3.9
	2	45.5	52.5	57.0	61.0	1.2	1.4	1.9	1.2
	3	60.5	70.5	75.5	78.5	0	0.7	0.8	1.3
	4	53.0	63.5	69.5	73.0	0.6	0	0	0.3
	5	63.5	71.5	75.0	77.5	0.4	2.5	3.0	3.3
	6	62.0	68.5	73.0	75.5	0.7	2.4	2.1	2.4
	7	43.5	51.5	57.0	60.5	0.3	2.5	3.6	4.3
	8	70.5	78.5	82.0	84.0	0.0	1.0	1.2	1.5
Cracked	9	63.0	68.5	70.5	72.0	0.4	1.7	2.0	2.8
	10	63.0	68.5	71.5	74.0	0.5	1.4	1.9	1.4
	11	75.5	78.0	....	81.5	0.8	2.6	...	2.4
	12	70.5	75.0	76.5	78.0	0	1.4	2.3	2.3
	13	62.5	69.5	73.0	75.0	0.2	0.5	.05	0.6
	14	70.0	72.0	....	74.5	0.2	1.3	...	1.7
	15	72.0	74.0	75.5	....	1.0	1.3	1.2	...
	16	64.5	69.5	72.0	73.5	0	0.6	0.6	0.4
	17	65.0	71.0	73.0	75.0	0.5	0.9	1.0	1.3
	18	66.0	72.0	75.5	77.5	0.4	1.2	1.6	1.5
	19	70.0	72.5	75.5	76.5	0.5	1.0	1.3	2.5
	20	59.5	66.5	70.0	73.0	0	1.0	2.0	1.5
	21	69.5	72.0	....	75.5	0.2	0.6	...	0.7
	22	67.5	71.5	....	75.5	0.8	2.0	...	2.7
	23	70.0	75.0	77.0	79.0	0	1.3	1.2	1.1
	24	70.0	74.0	76.5	77.5	0	0.7	1.0	0.9
	25	68.0	73.0	....	77.5	0.4	1.0	...	1.0
Blend of cracked and straight run	26	67.0	73.5	77.0	79.0	0.9	1.0	1.1	0.6
	27	67.0	73.0	75.5	77.5	0	1.4	1.9	2.0
	28	58.0	65.5	70.0	72.5	0.2	0.7	0.9	0.7
Catalytic polymer	29*	70.0	75.0	77.0	78.5	0.4	1.4	1.7	2.0
	30	82.5	84.0	85.0	84.5	0.3	0.3	0.3	0.7
Reformed	31	69.0	75.0	78.0	79.0	0.4	0.9	1.1	1.6
Averages—Items 1— 8 incl.		57.9	65.9	70.3	73.2	0.65	1.71	2.10	2.28
Items 9—25 incl.		67.4	71.9	74.3	75.9	0.35	1.21	1.46	1.55
Items 1—31 incl.		65.3	70.8	73.8	75.7	0.43	1.29	1.57	1.68

* Octane numbers obtained for a 1—1 blend with A-5 reference fuel. Octane number of reference fuel =40.5.

high solvency power. Since the mercaptans are removed from the gasoline in this case, rather than converted to other sulfur compounds which are equally bad or even worse than those originally present, it is to be expected that solutizer sweetening will result in an **improvement** in octane number and lead susceptibility as compared to the sour gasoline. A few data were presented[14] indicating that such is the case. We have since had the opportunity to examine a fairly large number of gasoline samples differing in type and origin, and the results obtained are presented in this paper.

PROPERTIES OF GASOLINE

Properties of the sour gasolines as received are given in Table 1. These include the A.S.T.M. distillation, A.P.I. gravity, bromine number, and sulfur contents. The straight-run gasolines represent samples from West Texas, New Mexico, Pennsylvania, and the Mid-Continent. The cracked gasolines represent samples from California, Montana, Arkansas, and Louisiana, in addition to those sections listed above.

A portion of each sample was sweetened with solutizer in the laboratory in the following manner. The gasoline was cooled to 0°C. and successively extracted in a separatory funnel with fresh 10 or 20 percent volume batches of precooled solutizer solution (6N potassium hydroxide, 3N potassium isobutyrate) until a sweet doctor test was obtained. In general, the gasoline was sweetened by two or three extractions. The sweetened gasoline was then filtered and immediately inhibited with 0.1 gram of α-naphthol per liter in order to prevent any deterioration prior to further testing. To minimize oxidation during the period of extraction, the air in the separatory funnel was displaced by nitrogen, and the entire procedure was carried out in the course of an hour's time or less. It has been our experience that gasolines of less than about 10 pounds Reid vapor pressure can be treated in this manner with a negligible loss of light ends. Nevertheless, for the purpose of the ensuing octane comparison between the solutizer sweetened and sour samples, a portion of the latter was put through an identical extraction procedure, substituting water for solutizer solution.

OCTANE DETERMINATION

Octane number determinations were carried out in accordance with A.S.T.M. method D357-38T in the presence of 0, 1, 2, and 3 cc. of tetraethyl lead (TEL) per gallon. At each lead concentration, the sour and solutizer sweetened samples were directly compared in the engine, thus allowing the detection of differences as small as 0.2 octane numbers, as set forth in Sections 14(b) and 16 of the A.S.T.M. procedure. In this way, a reliable determination of the effect of solutizer sweetening, as compared to the sour gasoline, was obtained.

The results for the various gasolines are presented in Table 2. The octane number of the sour gasoline is given to the nearest half unit, while the difference in octane number between the solutizer sweetened and sour gasoline is reported in tenths of units. It will be noted that in every case the octane number was improved as a result of solutizer sweetening, or else unchanged. The average increase in unleaded octane number for the 31 samples was 0.42 units, and with 1, 2, and 3 cc. TEL per gallon, the corresponding increases were 1.29, 1.57, and 1.68 octane numbers. The average octane increase was somewhat greater for the straight-run gasolines (items 1-8) than for the cracked gasolines (items 9-25). The average octane numbers of all the gasolines are plotted

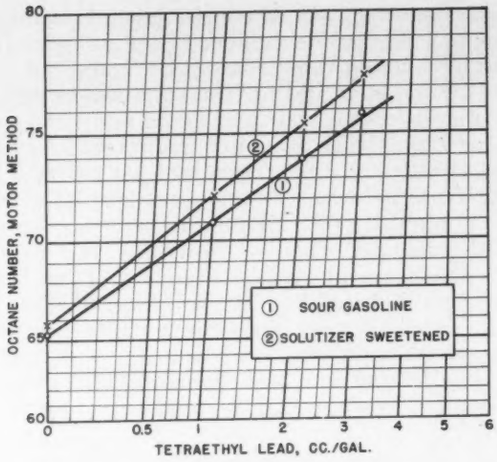

FIGURE 1

Average octane numbers for 31 different gasolines showing the improvement in octane number and lead susceptibility resulting from solutizer sweetening.

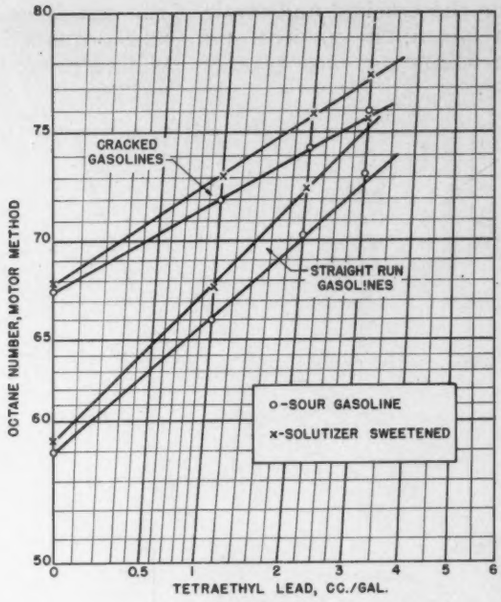

FIGURE 2

Average octane numbers for 17 cracked gasolines and for 8 straight run gasolines showing the improvement in octane number and lead susceptibility resulting from solutizer sweetening.

on an ethyl blending chart[5] shown as Figure 1, while the averages for the cracked and for the straight-run gasolines are shown in Figure 2.

Plots, similar to those of Figures 1 and 2, were prepared for each gasoline, and the amounts of TEL that had to be added to the solutizer-sweetened gasoline in order to match the octane number of the sour gasoline doped with 0.5, 1, 2, and 3 cc. of TEL per gallon, respectively, were determined. This is shown in Table 3 which includes also the percentage saving in TEL as a result of solutizer sweetening, compared to the sour gasoline. The mean percentage saving, shown in the last column of the table, is the average of the values at the four lead concentrations. These values vary considerably for the different gasolines (9.3 to 65.3 percent), but appear to be correlated with the mercaptan content of the sour gasoline. This is illustrated by Figure 3 where the mean TEL saving is plotted against the logarithm of the mercaptan concentration. On the whole, the points fall within or close to the smooth band. It may be noted that the mean TEL saving appears to be substantially the

TABLE 3

Comparison of TEL Requirements of Sour and Solutizer Sweetened Gasolines

TYPE OF GASOLINE	Item No.	cc. TEL/Gallon required for Solutizer Sweetened Gasoline to Give the Same Octane Number as the Sour Gasoline Containing Various Amounts of TEL				Savings in TEL resulting from Solutizer Sweetening, Compared with the Sour Gasoline, Percentage				
		0.5 cc. TEL/Gal. in Sour Gasoline	1 cc. TEL/Gal. in Sour Gasoline	2 cc. TEL/Gal. in Sour Gasoline	3 cc. TEL/Gal. in Sour Gasoline	0.5 cc. TEL/Gal. in Sour Gasoline	1 cc. TEL/Gal. in Sour Gasoline	2 cc. TEL/Gal. in Sour Gasoline	3 cc. TEL/Gal. in Sour Gasoline	Mean
Straight run	1	0.13	0.36	0.86	1.32	74	64	57	56	62.8
	2	0.37	0.70	1.55	2.25	26	30	22.5	25	25.9
	3	0.45	0.80	1.78	2.62	10	20	11	12.7	13.4
	4	0.43	0.91	1.86	2.78	14	9	7	7.3	9.3
	5	0.32	0.64	1.27	1.80	36	36	36.5	40	37.1
	6	0.30	0.65	1.34	1.02	40	35	33	36	56.0
	7	0.33	0.68	1.33	1.95	54	32	33.5	35	33.8
	8	0.42	0.82	1.60	2.29	16	18	20	23.7	19.4
Cracked	9	0.29	0.62	1.22	1.77	42	38	39	41	40.0
	10	0.33	0.70	1.43	2.08	34	30	33.5	30.7	32.0
	11	0.16	0.34	0.76	1.11	68	68	62	63	65.3
	12	0.31	0.60	1.13	1.61	38	40	43.5	46.3	42.0
	13	0.44	0.90	1.81	2.68	12	10	9.5	10.7	10.5
	14	0.25	0.49	1.00	1.44	50	51	50	52	50.8
	15	0.10	0.35	0.91	1.42	80	65	54.5	52.7	63.0
	16	0.45	0.89	1.76	2.60	10	11	12	13.3	11.6
	17	0.35	0.76	1.57	2.30	30	24	21.5	23.3	24.7
	18	0.36	0.75	1.52	2.22	28	25	24	26	25.8
	19	0.26	0.58	1.21	1.79	48	42	39.5	40.3	42.5
	20	0.41	0.81	1.57	2.26	18	19	21.5	24.7	20.8
	21	0.37	0.78	1.59	2.31	26	22	20.5	23	22.9
	22	0.22	0.49	1.04	1.52	56	51	48	49.3	51.1
	23	0.39	0.76	1.49	2.10	22	24	25.5	30	25.4
	24	0.41	0.71	1.60	2.28	18	29	20	24	22.8
	25	0.35	0.75	1.54	2.27	30	25	23	24.3	25.6
Blend of cracked and straight run	26	0.55	0.77	1.68	2.51	34	23	16	16.3	22.3
	27	0.35	0.71	1.35	1.92	30	29	32.5	36	31.9
	28	0.44	0.89	1.78	2.67	12	11	11	11	11.3
Catalytic polymer	29	0.30	0.65	1.27	1.81	40	37	36.5	39.7	38.3
	30	0.29	0.68	1.65	2.25	42	32	17.5	25	29.1
Reformed	31	0.36	0.75	1.53	2.22	28	25	23.5	26	25.6
Averages:										
Items 1— 8 incl.		0.34	0.70	1.46	2.12	31.3	30.5	27.6	29.5	29.7
Items 9—25 incl.		0.32	0.66	1.36	1.99	35.9	33.7	32.1	33.8	33.9
Items 1—31 incl.		0.33	0.69	1.42	2.07	33.8	31.4	29.2	31.1	31.4

same for the cracked and straight-run gasolines for a given mercaptan concentration, as shown by the average points for each type of gasoline plotted in Figure 3.

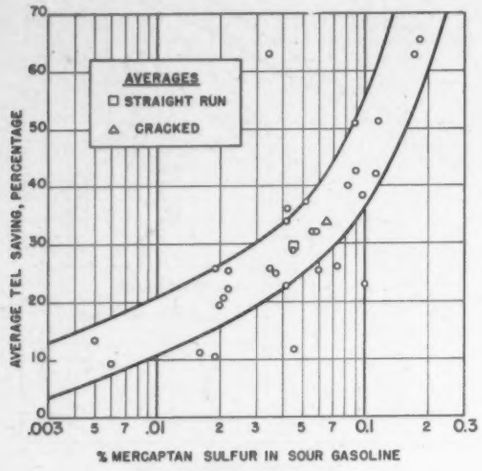

FIGURE 3

Average TEL saving as a function of the % mercaptan sulfur in the sour gasoline.

In comparing the quantity of lead that must be added to the sour and to the solutizer-sweetened gasolines to obtain equivalent octane numbers, the percentage saving in TEL, resulting from the solutizer sweetening of a given gasoline, is roughly independent of the quantity of TEL used, as shown by the last five columns of Table 3. The actual saving in TEL, expressed either as cc. per gallon or as cents per barrel, however, will of course depend on the extent to which the octane number of the gasoline is to be raised by leading. Comparing the amounts of TEL required for the sour and for the solutizer-sweetened gasolines in order to obtain an octane number 5 units higher, for example, than that of the untreated (sour) gasoline, it is found that the actual saving in TEL, resulting from solutizer sweetening, is now a function of the quantity of TEL required for leading the untreated gasoline. This is shown by the data of Table 4 which are plotted in Figure 4. Thus, if the sour gasoline required 0.5, 1.0, or 1.5 cc. of TEL per gallon in order to raise the octane number 5 units, solutizer sweetening plus leading to the same octane number would result in a lead saving (at 0.25 cents per cc.) amounting to about 1, 3, or 5 cents per barrel, respectively.

TABLE 4

Comparison of TEL Requirements of Sour and Solutizer Sweetened Gasolines

TYPE OF GASOLINE	Item No.	TEL Required to Obtain an Octane Number 5 Units Higher Than That of the Sour Gasoline, cc./Gal.		TEL Saving Resulting from Solutizer Sweetening, Compared to Sour Gasoline	
		Four Sour Gasoline	For Solutizer Sweetened Gasoline	cc./Gal.	¢/bbl. (at 0.25¢/cc.)
Straight run...	1	0.83	0.28	0.55	5.78
	2	0.60	0.38	0.22	2.31
	3	0.34	0.30	0.04	0.32
	4	0.32	0.27	0.05	0.53
	5	0.50	0.32	0.18	1.89
	6	0.57	0.35	0.22	2.31
	7	0.50	0.34	0.16	1.68
	8	0.47	0.38	0.09	0.95
Cracked.....	9	0.98	0.67	0.31	3.26
	10	0.80	0.55	0.25	2.63
	11	2.50	0.94	1.56	16.4
	12	1.37	0.80	0.57	5.99
	13	0.60	0.52	0.08	0.84
	14	4.45	2.05	2.40	25.2
	15	4.70	2.30	2.40	25.2
	16	1.00	0.89	0.11	1.16
	17	0.84	0.63	0.21	2.21
	18	0.66	0.48	0.18	1.89
	19	1.70	1.03	0.67	7.04
	20	0.56	0.46	0.10	1.05
	21	2.39	1.92	0.47	4.94
	22	1.30	0.66	0.64	6.72
	23	1.00	0.76	0.24	2.52
	24	1.22	0.96	0.26	2.73
	25	0.93	0.70	0.23	2.42
Blend of cracked and straight run.	26	0.63	0.44	0.19	2.00
	27	0.79	0.55	0.24	2.52
	28	0.49	0.43	0.06	0.63
Catalytic polymer....	29	1.05	0.67	0.38	3.99
	30	6.0	6.0	.....	....
Reformed.....	31	0.74	0.55	0.19	2.00
Averages:					
Items 1— 8 incl....		0.48	0.32	0.16	1.68
Items 9—25 incl....		1.17	0.78	0.39	4.10
Items 1—31 incl....		0.81	0.57	0.24	2.52

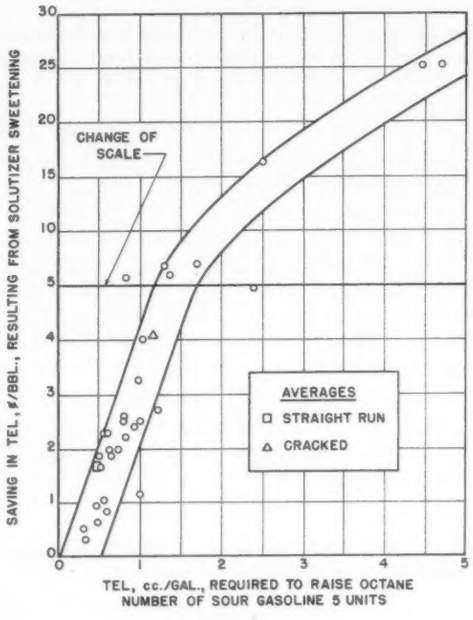
CHANGE OF SCALE
AVERAGES
□ STRAIGHT RUN
△ CRACKED
SAVING IN TEL, ¢/BBL., RESULTING FROM SOLUTIZER SWEETENING
TEL, cc./GAL., REQUIRED TO RAISE OCTANE NUMBER OF SOUR GASOLINE 5 UNITS

FIGURE 4

TEL saving, as c/bbl. at 0.25c/cc, as a function of the lead required to raise the octane number of the sour gasoline 5 units.

In all the above cases, we have compared the lead response of the solutizer sweetened gasoline with that of the untreated gasoline. If, however, solutizer sweetening were compared with sweetening methods that convert mercaptans substantially to disulfides, the lead savings illustrated in Figures 3 and 4 would be appreciably increased in many cases.

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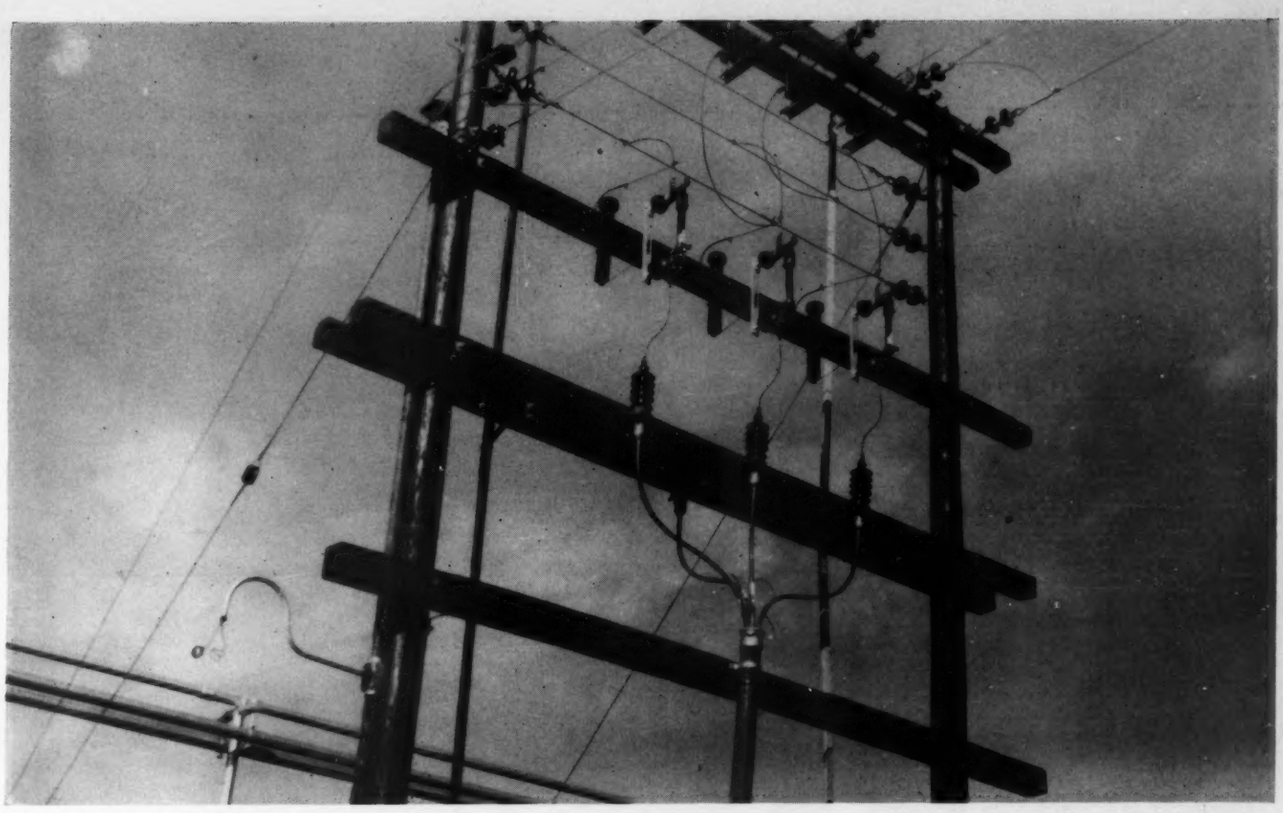


Two 13,000-volt transmission lines feed electric power into one overhead terminal, from which power lines are taken underground to the single transformer station. By using two transmission lines, the hazard of having all power shut off because of line failure is reduced.

This overhead terminal is on the side of the plant yard where there is least congestion, a precaution against the possibility of injury to both service company employees and plant employees, since power company men are not familiar with processes and plant routine.

UNDERGROUND FOR

Safer Electric Service

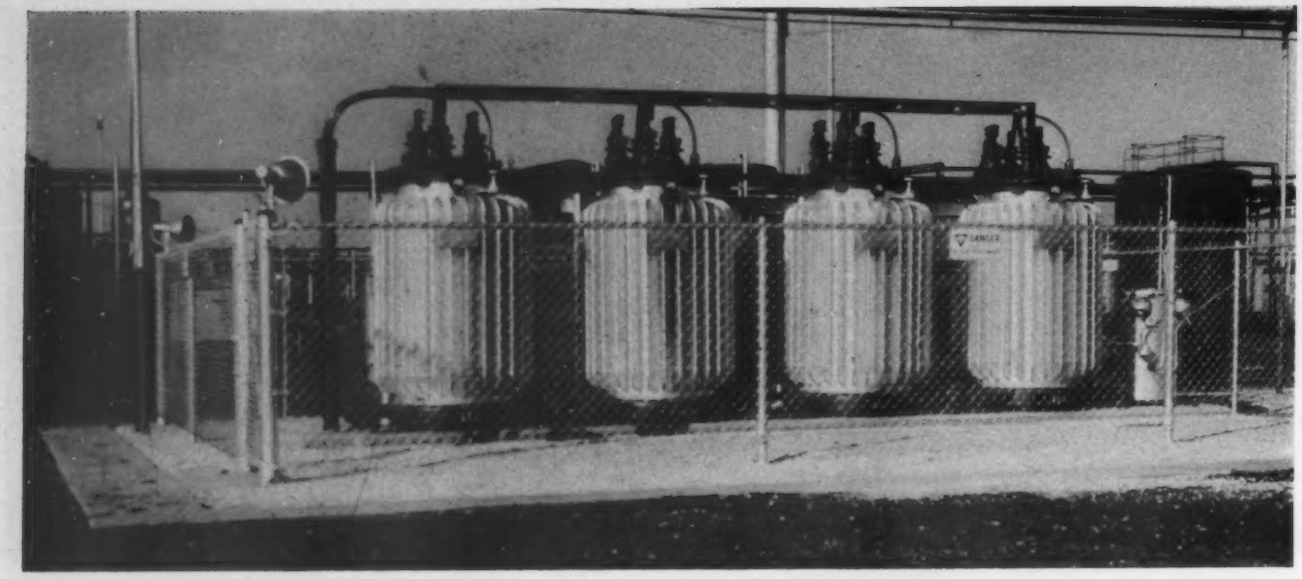
IN the drive to make the refining plant a safer place to work, shifting the electric power lines into conduit and replacing several overhead transformer stations by one substation is a step which also adds to the appearance of the property.

The single substation permits reducing power to its required voltage at one point, whereas the overhead transformers often required high-voltage lines to traverse areas where highly volatile vapors were under processing. Since the service of the power company ends at the metering station adjacent to the transformer bank, the hazard existing when men not familiar with refinery processing must come into the property is lessened. For the plant personnel, conduit wiring removes the danger of overhead wiring.

The pictures herewith represent the methods used by Continental Oil Company to transport all electric power underground in its Wichita Falls plant. Two 13,000-volt transmission lines come to the plant and converge overhead at one point. From there all wiring goes underground, emerging at each outlet adjacent to the device which requires power.

Ten main and auxiliary power circuits tie into the switch panel adjacent to the transformer station. The cables are carried in conduit from 1¼ inches to 4 inches in diameter. Three circuits are in galvanized pipe conduit and one circuit is in a composition conduit which can be laid in a curve. This wiring provides 1935 horsepower, which have 1090 connections to motors and other devices.

All power taken from the substation is at 440 voltage, required for the greater number of motors. For the few instances of 220- and 110-volt uses, small dry-core transformers are used to gain the reduction.

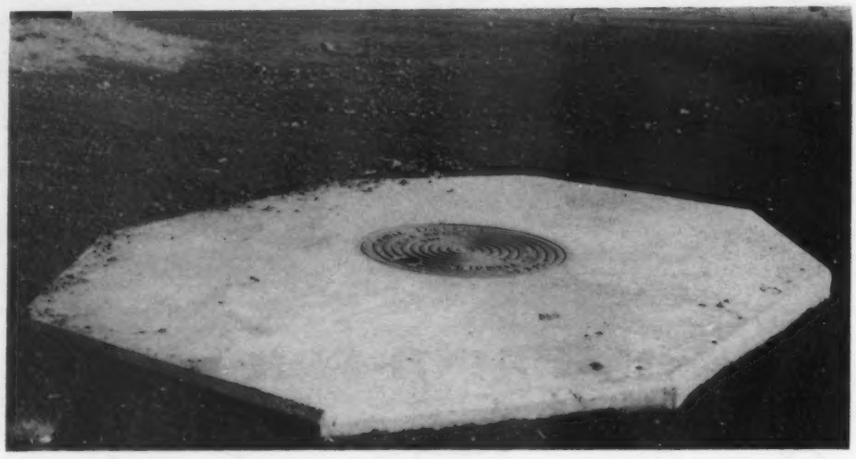


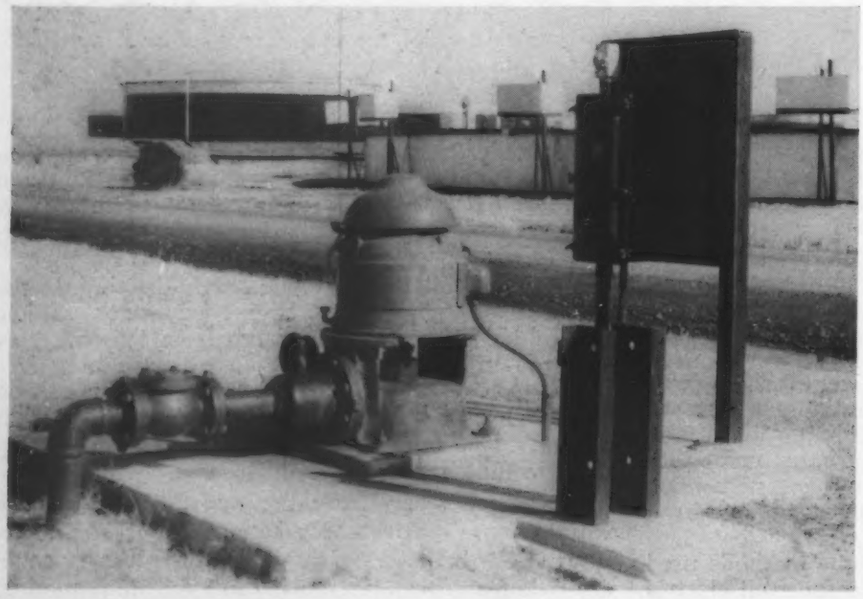
The conduit transmission system permits placing all transformers at one substation. This reduces voltage to plant requirements at a point removed from possible vapors, a safety hazard reduction in comparison with previous overhead lines with transformers placed near the need of voltage reduction.

Metering is done on the secondary side of the transformer station.

The substation consists of four 333 kva transformers set on a concrete base 14 by 23 feet. Three are in constant use with one for stand-by. The station is inclosed with a woven wire fence, one side of which is built as a unit, so it can be removed when it is necessary to to replace a transformer. Surface on this side of the fence is gravel coated to support the weight of a loaded truck.

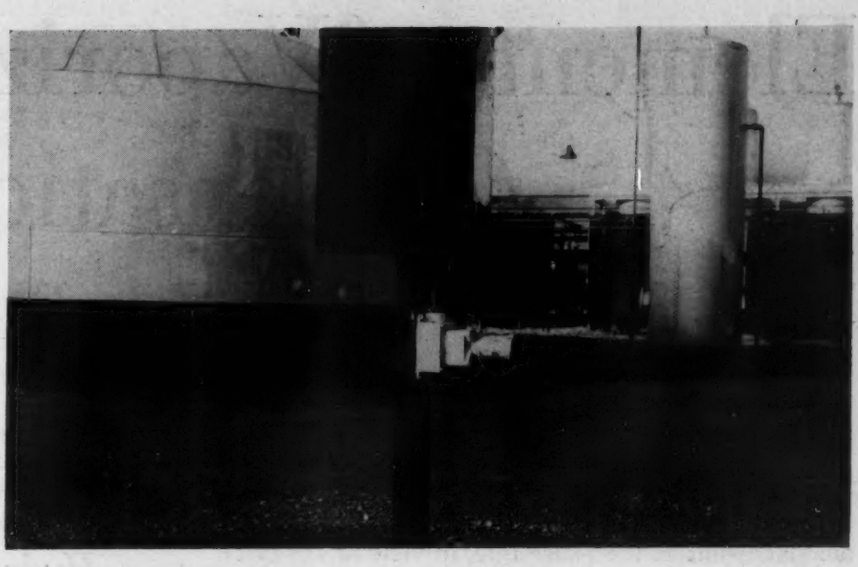
The panel for switches and the master meter is adjacent to the substation.





Above: **Manhole boxes** are excavated 6 feet below the ground level and lined with brick and concrete. The brick is inserted end wise through the wall, so it can be removed as occasion arises for installing additional leads.

Left: **The installation** at this isolated water well shows how the service line comes underground to the switch panel and then to the motor.



Vapor proof outlets are placed on the plant yard to allow operation of motor driven welding equipment without danger.

All motors are grounded by connection with moisture laden soil. In some instances rods are driven 8 feet into the ground and connected to the motor with copper wire.

Static protection for tanks which hold volatile material is drained by attaching a copper wire to a manhole flange bolt and then to a ground post.

Elements of Vaporization and Condensation

Part II. The Application of Phase Equilibria Principles to the Behaviour of:

1. Water—Hydrocarbon Systems

2. Mixtures of Two or More Hydrocarbons

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University of Oklahoma

IN a recent paper,[2] several simple systems such as steam, water and inert gases were analyzed from the standpoint of the phase rule, in view of the fact that the steam boiler plays an important part in the operation of every refinery and gasoline plant. The Gibbs[1] phase rule can also serve as a useful tool in the study of equilibria between hydrocarbon vapors and liquids, a sound understanding of which is needed in the solution of problems pertaining to the design of absorption, distillation and fractionation equipment. The rule may be stated mathematically as follows:

$$F + P = C + 2$$

Where F = the number of degrees of freedom or variance
P = the number of phases
C = the number of components or chemical compounds which go to make up the system

WATER-HYDROCARBON SYSTEM

I. Liquid State

Since steam is used in the distillation of various hydrocarbons, it is well to consider the phase relationships of these components. Most hydrocarbons are only slightly miscible in water i.e., they dissolve to a very small extent. In the vapor phase, steam and hydrocarbons are readily mixed, although stratification may occur in the absence of convection currents provided the hydrocarbons are of different density than that of water vapor.

Let us consider a cylinder containing a gallon each of water and liquid pentane (a natural gasoline component) on which a frictionless piston is exerting a pressure of 16.95 pounds per square inch absolute or 2.25 pounds gage (based on an atmospheric pressure of 14.7 pounds per square inch absolute). So long as the temperature of the cylinder is kept below 100° F., there will be no tendency for vapor to form, and the piston will lay on the surface of the liquid (Figure 1). To make a check up on the state of the system, it is found by reference to the phase rule that the system is fixed since there are two liquid phases, two components (pentane and water) and two degrees of freedom have been fixed, namely temperature and pressure.

II. Vaporization of Pentane Only at Constant Pressure

As soon as the temperature is raised a differential amount above 100° F., the constant pressure piston is elevated due to the formation of vapor. Each component will exert its own vapor pressure independent of the other component. The pentane exerts a vapor pressure of 16 pounds per square inch absolute and the water 0.95 pounds, therefore the number of pentane molecules leaving the liquid as vapor will be 1600 compared to every 95 water molecules, or more accurately stated the ratio of pentane molecules to water molecules being transformed into vapor will be 16/0.95. In other words one must deal with extremely large numbers of molecules such as 6.06×10^{23} molecules for every gram molecular weight, which in the case of water is 18 grams or .0397 pounds. If a person could count the first few molecules which leave the pentane-water system, by means of a very high powered microscope, he might find variations from this ratio, however from the law of probability, this variation from the statistical average would rapidly approach zero as more and more vapor molecules are counted.

The piston will continue to rise as long as the temperature is held slightly above 100° F. until all of either the pentane or water (or both) disappear from the liquid state. In this case the initial quantity

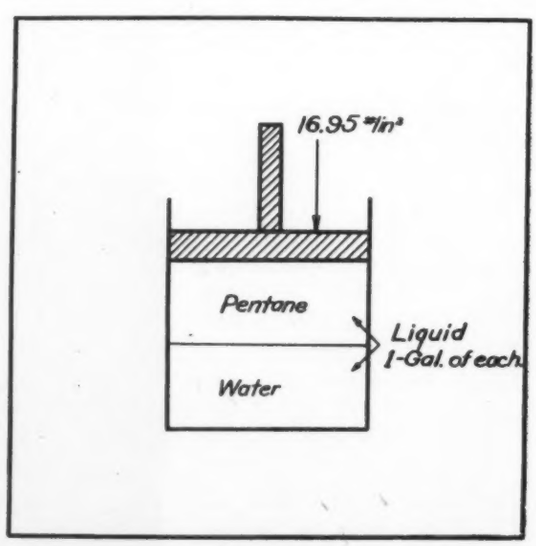

FIGURE 1
Liquid state. Temperature 100° F. or lower. Pressure=16.95 pounds per square inch.

of each component is one gallon. One gallon of pentane at 60° F. is equal to 0.632 (sp. gr.) x 8.33=5.27 pounds, or 5.27/72 = .0733 pound molecular weights (pound mols), as pentane has a molecular weight of 72. One gallon of water = 8.33 pounds or 8.33/18 = .4625 pound mols. Since 16 pound mols of pentane

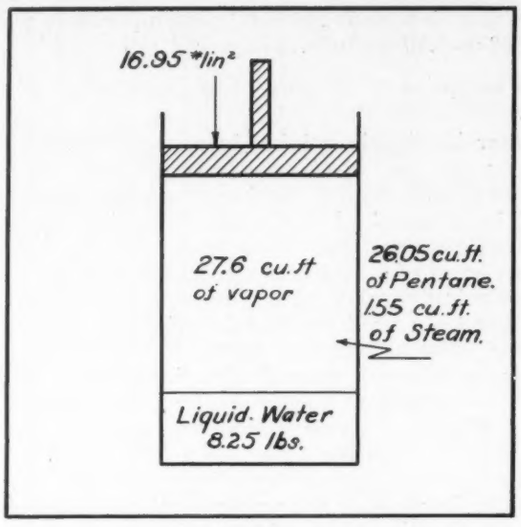

FIGURE 2
Partial vaporization at constant pressure of 16.95 Pounds and 100° F.

will vaporize while 0.95 pound mols of water are also turning to vapor, there will be, in this case, only $\left(\frac{.95}{16} \times .0733\right) = .00435$ pound mols of water vapor formed. There will be (.4625—.00435) = .45815 pound mols of liquid water remaining in the cylinder or

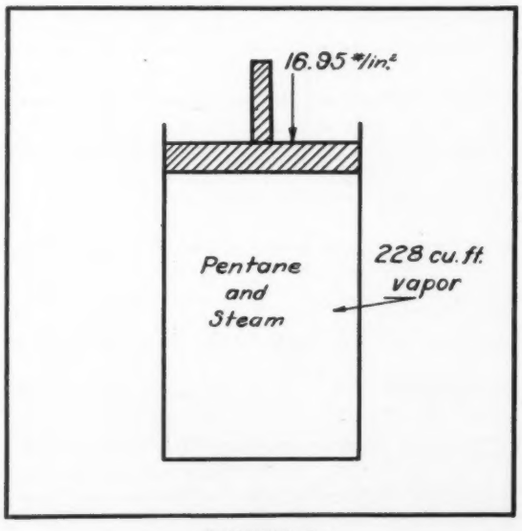

FIGURE 3
Complete vaporization at 16.95 pounds pressure and 211.8° F.
Partial Pressure Steam=14.63 Pounds
Partial Pressure Pentane= 2.32 Pounds

0.45815 x 18 = 8.25 pounds of water when all of the pentane has vaporized. (Refer to Figure 2.)

The vapor space will now be filled with .0733 pound mols of pentane and .00435 pound mols of water vapor at 16.95 pounds per square inch absolute and 100° F. The combined pentane and water in the vapor (.07765 mols) will occupy

$$\underbrace{.07765}_{\text{lb. mols}} \times \underbrace{380}_{\frac{\text{std. cu. ft.}}{\text{lb. mol}}} \times \underbrace{\frac{560}{520}}_{\text{abs. temp. correction}} \times \underbrace{\frac{14.7}{16.95}}_{\text{abs. pr. correction}} = 27.60 \text{ cu. ft.}$$

while 8.25 pounds of water will be remaining as liquid in the bottom of the cylinder. During the interval when pentane and water existed both in liquid and vapor form, the state of the system was fixed regardless of the relative quantities of each one present in the two phases. In other words 3 phases were present (2 liquid and 1 vapor); 2 components (pentane and water), therefore to fix the state of the system, it was necessary only to set one degree of freedom, namely the temperature or the pressure.

III. Complete Vaporization of the Water-Pentane Mixture

In order to convert all of the water into steam it will be necessary either to increase the temperature or to decrease the pressure.

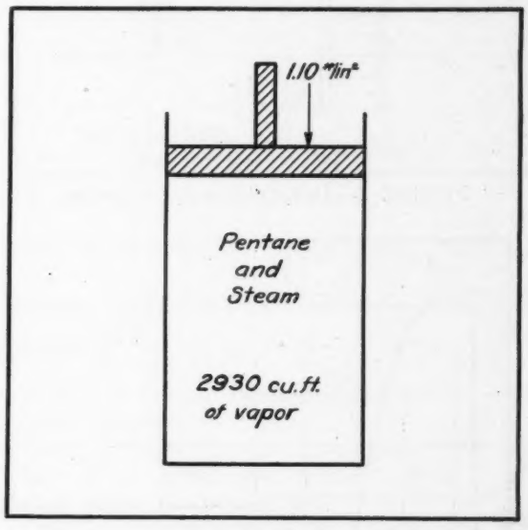

FIGURE 4
Complete vaporization at 1.10 pounds pressure and 100° F.
Partial Pressure Steam=0.95 Pounds
Partial Pressure Pentane=0.15 Pounds

(a) *At Constant Pressure:*

If the pressure is held constant, the temperature will have to be increased sufficiently to raise the vapor pressure of the water to that of the partial pressure of steam. At the time all of the water has evaporated, there will be 0.0733 pound mols of pentane and 0.4625 pound mols of water in the vapor space or 0.5358 pound mols of vapor. The total pressure is still 16.95 pounds and the partial pressures of the pentane vapor and steam are

$$\frac{.0733}{.5358} \times 16.95 = 2.32 \text{ lbs.} \quad \text{and} \quad \frac{.4625}{.5358} \times 16.95 = 14.63 \text{ pounds}$$

respectively. For the water to exert 14.63 pounds vapor pressure, a temperature of 211.8° F. is needed. (Figure 3.)

(b) *At Constant Temperature:*

If total vaporization is to take place at 100° F., the piston pressure will have to be reduced so that the partial pressure of the water vapor is kept at

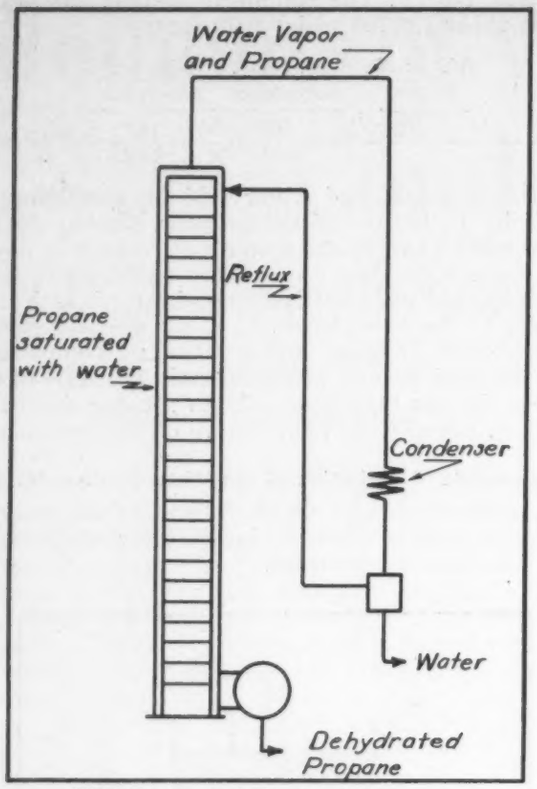

FIGURE 5—*Dehydration of Propane*

0.95 pounds with all of the water evaporated. The steam will occupy

$$\frac{.4625 \text{ (mols steam)}}{.5358\text{(mols steam and pentane)}} \times 100 = 86.2\%$$

of the vapor volume and also exert 86.2 percent of the total pressure. Since the partial pressure of the steam is 0.95 pounds the total piston pressure will be .95/.862 = 1.10 pounds. (Figure 4.)

An exception to the rule: The Dehydration of Propane:

Water is slightly soluble in practically all hydrocarbons. In the fractionation of propane, a small amount of dissolved water is often found to be present. The removal of this water from the propane is required before it can be sold as domestic fuel as the presence of water is apt to cause freezing in the gas reducing regulators. Drying agents such as silica gel have been used for the dehydration of propane, but the most satisfactory method of water removal has been effected through fractionation. Although propane has almost 200 times the vapor pressure of water, dissolved water in propane does not behave according to Raoult's Law, but to the contrary, the dissolved water proves to be more volatile than the propane. As a result the water is taken out overhead from the fractionating column. (Figure 5.)

MIXTURES OF HYDROCARBONS

As a rule liquid hydrocarbons are miscible in each other in all proportions, hence their behaviour is

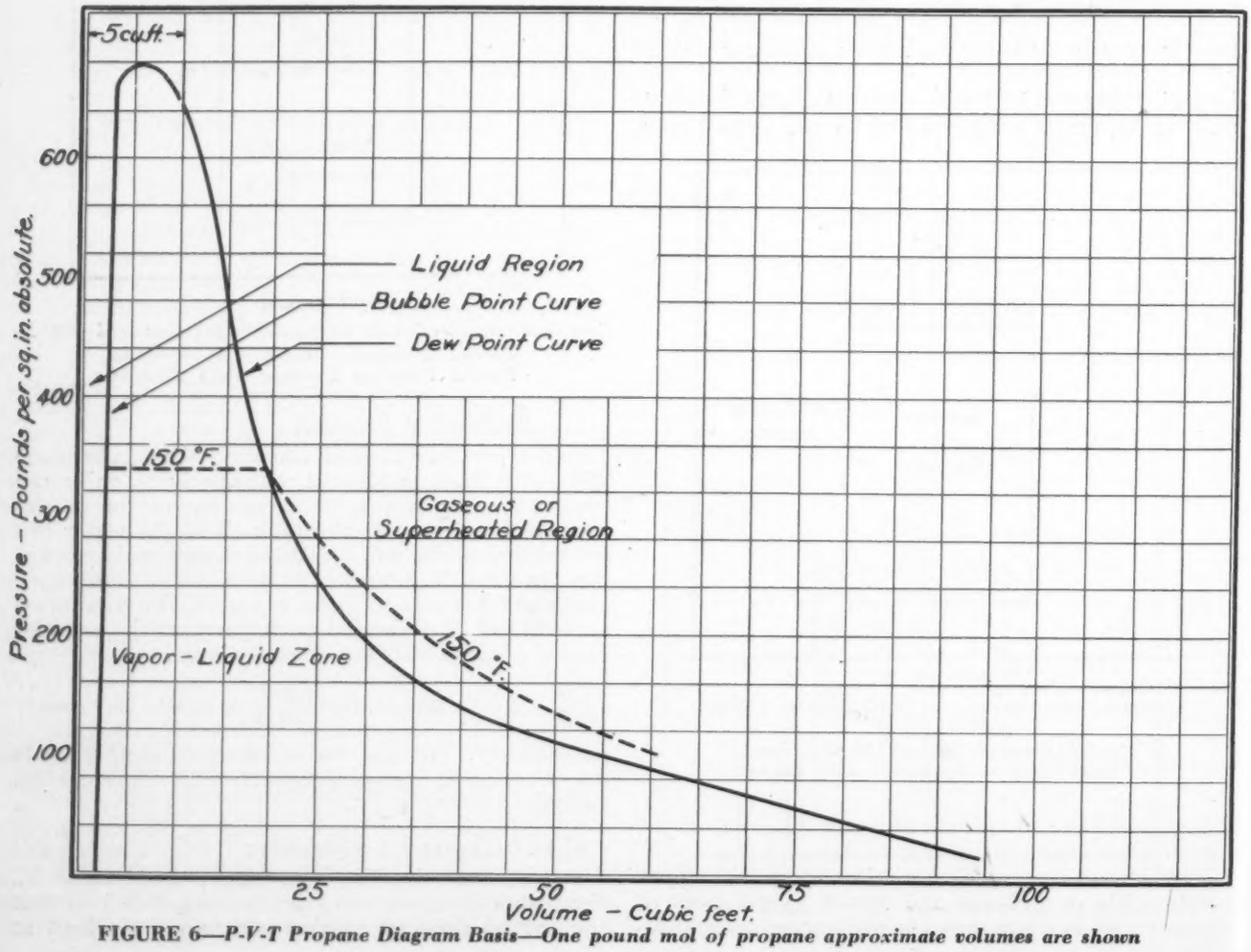

FIGURE 6—*P-V-T Propane Diagram Basis—One pound mol of propane approximate volumes are shown*

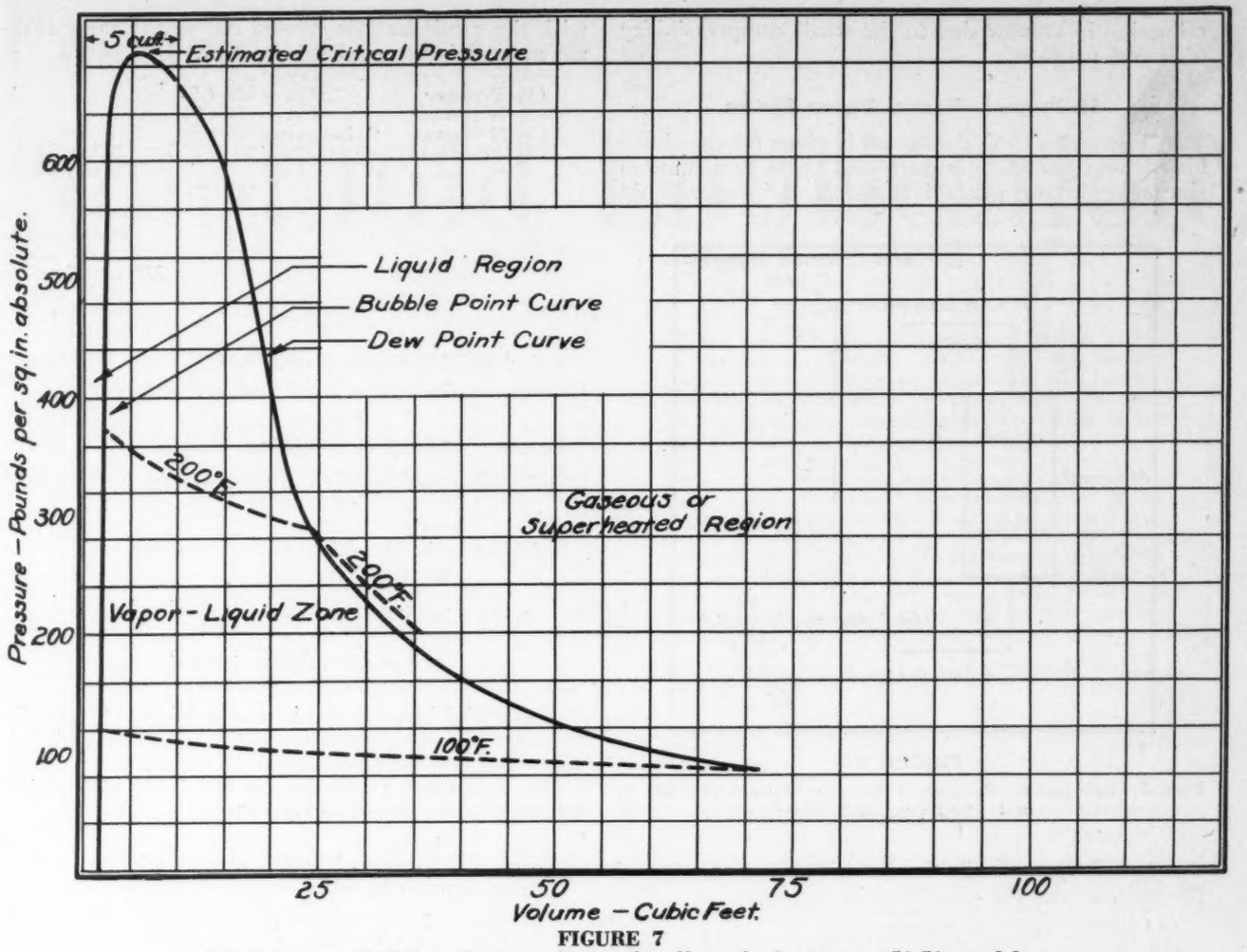

FIGURE 7

P-V-T Propane-N Butane Diagram Basis—One lb. mol of mixture (50-50) molal percentages. Approximate volumes are shown.

somewhat different from that of immiscible or partially miscible liquids. Each component in the liquid mixture, instead of exerting its full vapor pressure, has a partial pressure effect equal to product of its vapor pressure by the mol fraction of the same component. This law is known as Raoult's and is a special case of Henry's Law.

Mathematically these laws can be expressed as follows:

(1) Raoult's Law (expressing the equilibrium relationship between vapor and liquid.)

$$\pi y = p x$$

Where π = Total pressure on the system
y = Mol fraction of any component in the vapor
p = Vapor pressure of the same component in the pure state
x = Mol fraction of the same component in the liquid

The partial pressure of any component in the vapor is the product (πy) and the partial pressure of the same component in the liquid is (px).

(2) Henry's Law

$$y = Kx$$

Where y = Mol fraction of any component in the vapor
K = Proportionality or equilibrium coefficient
x = Mol fraction of the same component in the liquid

This law is more general in scope than Raoult's since it satisfies all conditions, the value of "K" being determined experimentally. In the absence of "K" values, Raoult's Law does provide a convenient tool for making calculations in certain ranges of pressure, temperature and solubility relationships.

P-V-T RELATIONSHIPS OF A HYDROCARBON

One of the most common methods of presenting the phase relationships of vapors and liquids is to plot isotherms (constant temperature lines) on the pressure-volume planes. Unless such a graph can be seen in three dimensions (P-V-T), a true picture of these relationships cannot be clearly obtained, hence the importance of making solid scale models. It is well to remember that each isotherm is in a different (P-V) plane.

(1) Propane

The pressure-volume-temperature relationships for propane are shown on a semi-quantitative scale in Figure 6. By taking a pound mol of propane as a gas and compressing it isothermally from a low pressure at 150° F., the hydrocarbon is found to follow approximately the perfect gas law until it reaches the dew point curve, the boundary between the gaseous and the vapor-liquid regions. From this point condensation takes place at a constant pressure of 340 pounds per square inch absolute and 150° F. until all the propane is condensed as liquid. Further compression at 150° F. causes a very slight

reduction in volume due to the small compressibility of liquid propane.

II. Propane—Normal Butane System

In Figure 7 a P-V-T diagram is given for the above binary mixture of hydrocarbons. There is a marked similarity in the general shape of the vapor-liquid

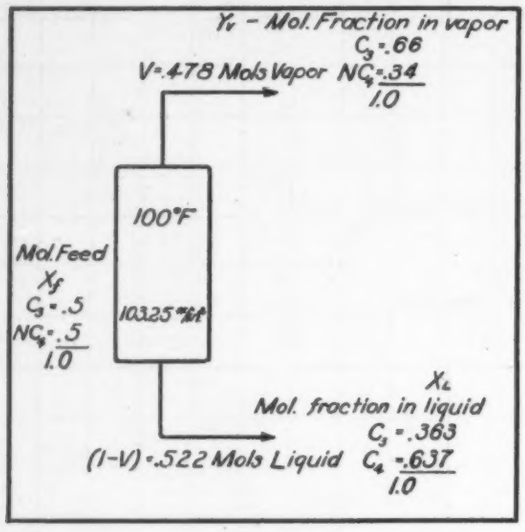

FIGURE 8

Partial Vaporization Propane-N Butane Mixture at 100° F. and 103.25 pounds pressure.

dome as well as the isotherms with the exception of the path across the vapor-liquid region.

(a) *Dew Point Calculation*

When this mixture is compressed at 100° F., the first drop of liquid which condenses is not pure butane, although the liquid droplet is richer in butane than the vapor from which it is condensed. If the vapor consists of a 50-50 molal mixture of propane and normal butane, the composition of the first drop and the pressure can be calculated for the 100° F. isotherm by setting up an equilibrium equation for each component.

Partial Pr. in Vapor = Partial Pr. in Liquid
Total Pr. × mol frac in vapor = vap. pr. × mol frac in liquid

$$\pi\, y = p\, x$$

(1) (Propane) $\pi \quad 0.5 = 188\ x_3$
(2) (N Butane) $\pi \quad 0.5 = 55\ x_4$
(3) $x_3 + x_4 = 1$ or $x_4 = 1 - x_3$
(4) N Butane $\pi \quad 0.5 = 55(1 - x_3)$
(5) Subtracting (4) from (1) $0 = -55 + 243x_3$
$x_3 = 55/243 = .226$ Mol fraction of propane in first drop
Substituting in (3) $x_4 = .774$ mol fraction of N butane in first drop
Substituting in (1) $\pi = \dfrac{188\ (.226)}{0.5} = 85$ lb./sq. in. Total pressure

(b) *Bubble Point or Total Condensation*

Unlike the single hydrocarbon, the mixture will require a higher pressure to bring about complete condensation. The calculation of this pressure and the composition of the bubble of vapor in equilibrium with the condensate is carried out in the same manner as in the case of the dew point.

$$\pi\, y = p\, x$$

(1) Propane $\pi\, y_3 = 188\ (.5)$
(2) N Butane $\pi\, y_4 = 55\ (.5)$
(3) N Butane $\pi(1 - y_3) = 55\ (.5)$
(4) Adding (3) and (1) $\pi = 94 + 27.5 = 121.5$ lb./sq. in. Total pressure

$$y_3 = \frac{188\ (.5)}{121.5} = .773$$ mol fraction of propane in vapor bubble

$y_4 = 1 - y_3 = .227$ mol fraction of N Butane in vapor bubble

(c) *Partial Condensation at 103.25 Pounds Pressure (Midway between dew point and bubble point)*

$$\pi\, y = p\, x$$

Propane $103.25\ y_3 = 188\ x_3$
N Butane $103.25\ y_4 = 55\ x_4$
N Butane $103.25\ (1 - y_3) = 55\ (1 - x_3)$

Adding each side of 1st and 3rd equations

$$103.25 = 55 + 133\ x_3$$

$x_3 = .363$ } Composition of
$x_4 = .637$ } Condensate

$y_3 = .66$ } Composition of
$y_4 = .34$ } Vapor

A material balance can be made, Figure 8, in order to determine the fraction of the mixture which is vaporized at 103.25 pounds and 100° F.

The balance for propane, on the basis of 1 mol of mixture fed to the separator, is:

	Input	Output	
		Vapor	Liquid
Propane	(1) (.5)	= V.66	+ (1 − V) (.363)
Butane	1 (.5)	= V.34	+ (1 − V) (.637)
	V = .462		1 − V = .538

Mols propane liquid = .538 x .363 = .195
Mols N Butane liquid = .538 x .637 = .343
.538

Volume of .462 mols of vapor at 103.25 lbs. and 100° F.

lb. mols	Std. Cu. Ft. / mol	Pr. Correction	Temp. Correction	
.462	380	14.7 / 103.25	560 / 520	= 26.9 cu. ft.

Volume of the liquid mixture in condensate

Propane $\dfrac{.195 \times 44}{62.4 \times .515} = .268$ cu. ft. of liquid

Butane $\dfrac{.343 \times 58}{62.4 \times .582} = .546$ cu. ft. of liquid

.814 total cu. ft. of liquid

Total volume liquid and vapor = 27.714 cu. ft.

CONCLUSION

These simple exercises should help to give the engineer an understanding of the principles underlying the design of plant equipment such as fractionators, absorbers, strippers, etc. In later papers of this series other principles and their application to the actual design and plant operation will be discussed.

Literature Cited

[1] Gibbs, J. Willard, Trans. Conn. Acad. Sci. 3, 228 (1876).
[2] Huntington, R. L. "Elements of Vaporization," Part I, "Refiner and Natural Gasoline Manufacturer," Jan. 1940.

Experimental Studies on

Non-Fluid Lubrication

PART 3

Running Properties of Bearing Metals

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THE paper presents a condensed review of the connections between lubrication and bearing metals with regard to the interests of the lubrication and mechanical research engineer. The first section essentially constitutes an application of the author's previous work on non-fluid lubrication on bearing-metal problems. In a second section problems of the physics of metals and bearing metallurgy are reviewed and a new bearing-metal theory is presented. In a third section certain fundamental points of metal strength, rupture and fatigue are reviewed. While principally problems of research and development as well as fundamental considerations are considered, they are demonstrated and developed on practical cases and applications are discussed.

1. *General remarks*—Engineering practice for a very long time has been acquainted with the phenomenon of the individual running properties of various bearing metals. The word "metal" is being used here in its widest meaning, not as a physical or metallurgical term. As a matter of course in the multitude of cases where the designer is little limited with regard to size and weight of the construction, its geometrical dimensions may be adjusted to the operating conditions so that fluid lubrication may be obtained with a good approximation. In fluid lubrication the requirements with regard to the metal practically are reduced to requirements of strength, i.e. strictly to problems of conventional mechanical engineering, if we disregard for the present—or include in "strength"—fatigue strength. The oil enters the problem just as a viscous fluid, required for providing fluid lubrication and that minimum film thickness sufficient for separating the peaks of the lubricated surfaces. The latter statement already shows that even the necessary oil viscosity is essentially determined by mechanical considerations, viz. the degree of smoothness of the surfaces. It is for this very sound reason that babbitt metal still dominates as a bearing metal, and it is worth mentioning that still a large number of bearing failures are due to poor mechanical design (e.g. deflections of the journal, poor alignment). From later paragraphs it will appear that improper structure and casting as well as machining defects ultimately belong under the same heading. Such failures are with one possible exception fundamentally inaccessible to physico-chemical improvement by the lubrication engineer or chemist. They amount to local overloading of the bearing and whereas the most economic cure is obvious, the use of a stronger bearing material is also possible.

BEARING DEVELOPMENT

The development of bearing metals, other than babbitt, follows two entirely different trends: increased economy or substitution of imported material by a domestic product, and increase of fatigue strength. The necessity for the latter arose with the increase of output per unit weight of the internal combustion engines. In this particular application of bearing metals conditions of thin film or even non-fluid lubrication plus fluctuating load are more frequent in ordinary operation, and thus the problem of the running properties of bearing metals gains both in scientific interest and practical significance.

In the present state of the problem an attempt at a rigid definition of "running properties" would serve no useful purpose. Both for fundamental research and practical application by the lubrication engineer it is best to understand by "running properties" the individual characteristics metals develop as structural members of the bearing, i.e. as journal or bearing materials. For obvious reasons our principal interest is focused on the bearing lining.

Since the work of Hardy and Doubleday,[1] who measured the static friction of normal paraffins, alcohols and fatty acids as functions of chain length and surface material and found very simple relationships, the phenomena of molecular surface orientation, first clearly recognized by Langmuir,[2] were gradually accepted as the leading principle in considerations on boundary lubrication. Hardy assumed identity of static friction with the kinetic non-viscous friction of practice and action of the solid surfaces over many molecules. It has been shown that Hardy's results on the connection between friction and molecular structure can be interpreted qualitatively on a molecular physical basis[3] without long distance actions, but the effect of the individual surface still remained obscure. Moreover, the possibility of a rational explanation of an effect does not answer the question whether the effect is real or not or whether it is the significant effect in a particular case. It does not answer either the important question, whether Hardy's "boundary lubrication," supposing his results were correct, is identical with non-fluid lubrication of practice. Various authors were unable to duplicate Hardy's experiments, a fact which suggests caution in their use. What is more important in our case, is the fact that there are definite indications that static friction is a different thing from the kinetic friction of practice,[4] and that in non-fluid lubrication the effects of immediate importance are chemical reactions between lubricant (or oxygen) and the surfaces or rather the few continually changing load-carrying peaks of the

surfaces.[5] We want to emphasize that this is not a straight negation of the orientation theory of non-fluid friction. There is ample reason—both theoretical and experimental—for assuming the preferential adsorption and orientation of polar additions (or combustion products) of an oil on the lubricated surfaces. However, the rôle of the adsorption layers is a more complex one, amounting to a chemical change of the surfaces in many cases and thus determining their behavior towards each other and with regard to wear and seizure.

THE METAL ASPECT

Engineering practice is largely accustomed to judge a bearing material from its frictional properties. It has been shown that there is no simple connection between friction and wear and that the coefficient of kinetic friction, other factors being equal, may depend on surface finish.[6] Because of this tendency of engineering practice and the complexity of the friction, wear and seizure problem, in the following paragraphs the bearing problem will be presented to the lubrication engineer in the light of more recent physico-chemical work. Whereas some preceding investigations,[6, 7] necessarily stressed the properties of the lubricant, we shall consider the problem here more from the metal aspect.

We shall consider first physico-chemical questions of the interaction of lubricant and metal and possible effects resulting therefrom. Second, we shall treat the metallurgical aspect of the problem, the considerations upon which bearing metals were developed and present a new theory of bearing metals. A third section will be devoted to a brief discussion of bearing fatigue.

2. *Physico-chemical interactions between lubricant and bearing metal*—On sliding two dry metal surfaces over each other the temperature at the points of actual contact tends to rise to the melting point of the lower melting metal with increasing rubbing speed and load. The increase in temperature is inversely proportional to the square root of the heat conductivity of the metals. On sliding two metals over each other, lubricated under boundary (thin film) conditions, the increase of the temperature at the high spots is roughly proportional to the coefficient of kinetic friction of the lubricant under the same conditions of experiment. The local temperatures reached under these conditions may well be of the order of 600° C. or more under conditions of boundary lubrication with a mineral oil.[8] The view that the actual area of contact is only a very small fraction of the surface, supported by many observations, has been confirmed experimentally.[5]

On polishing a solid by means of a polishing medium, surface flow or melting of the solid will occur when the melting point of the polisher (e.g. a metal oxide) is higher than the melting point of the solid. The relative hardness is comparatively unimportant. Flooding with a liquid does not prevent local heating. On polishing in air, due to intense local heating, in several cases surface oxidation was observed.[9] This has been shown also by means of electron diffraction patterns.[10]

Under conditions of thin film (yet essentially fluid) lubrication, in general, wear and grit particles in the oil stick to the lubricated surfaces due to electrostatic charges, forming there "secondary" asperities. This phenomenon results in local boundary lubrication and wear. Furthermore polish and surface flow occur.[11] Experiments on various lubricants, e.g. mineral oils, doped oils and straight addition agents, e.g. esters, also nitrogen compounds and mineral oils saturated with various gases, show that seizure is greatly promoted by acid content of the esters and is more determined by the chemical characteristics of the lubricant and its chemical reactions with the surfaces than by its surface orientation and coefficient of static friction. If the reaction is very violent and confined to the surface peaks, as in the case of chlorine from compounds, a smoother surface with a larger actual load-carrying area results. In the case of ammonia and other nitrogen compounds the same result is obtained by gradual running-in, whereas a rough surface results at high speeds and pressures. The effect of dissolved gases such as oxygen, nitrogen and carbon dioxyde is much the same as found by other authors in frictional experiments with metals in the atmospheres of these gases. Thus, the conclusion is justified that "oiliness" compounds and extreme pressure lubricants operate on the same principle in reacting chemically with the surfaces and contaminating them by compounds which require higher pressures (and consequently temperatures) to break down chemically and permit metal-to-metal contact, interdiffusion and seizure.[6, 7]

Discussion and applications to bearing-metal problems—The electrostatically-promoted type of wear may be counteracted by oil filters and electrical connection of the moving parts or by imparting electrical conductivity to the oil. This is automatically achieved by the addition of polar compounds. These substances are by nature or by their reactions with water conductive. Thus we see one reason why their effect could be attributed to protective adsorption layers which are certainly present but, in general, are not the principal cause of the effectiveness of polar additions.

PEAKS CARRY THE LOAD

In the case of non-fluid lubrication we are dealing with the "primary" roughness (peaks) of surfaces. It is these peaks which essentially carry the load, the valleys contributing to some extent, mostly by fluid lubrication. On the peaks kinetic friction obtains which is always accompanied by wear. For this reason the coefficient of kinetic friction is neither directly comparable to the coefficient of fluid (viscous) nor that of static friction. Obviously there enters into the coefficient of kinetic friction mechanical work done to the surface and any chemical reaction with the surface which changes its coefficient of friction. Thus the nature of the surface is very seldom defined. The coefficients of dry friction of metals found in literature are coefficients of contaminated surfaces and the values vary because the contaminations vary. Exceptional elaborate measurements will not be discussed here. The temperatures at the peaks are only limited by the melting point of the lower-melting surface, and the smaller the actual bearing area, the more easily is this temperature reached. High rates of reaction obtain at such temperatures and, in general, compounds will form between the surface material and the products of disintegration of the lubricant or the lubricant itself. The products of these reactions depend on the chemical properties of metal and lubricant, including its contaminations such as oxygen, oxidation products, carbon dioxide or any addition which will react proportional to its concentration.

It follows that we may obtain powerful abrasives and polishers, e.g., in the frequent cases where metal oxides may form, some of which, like SnO at 1625° C., have very high melting points. This may be used for improving the running-in process.

Honing operations are a familiar example of high-temperature reactions. Provided the polisher, in this case the stone, and the surface are smooth enough and

the remaining peaks of the order of the thickness of the lubricating firm, and provided further the point of melting or disintegration of the stone is high enough, the honed surface will melt or flow according to its melting point. The polisher may also react with the surface and produce an oxide film on it.

The contributions to the problem, offered by the papers summarized above, may be demonstrated on another example, investigated by Mougey and Almen.[12] While a 10 percent solution of Na-oleate in water proved to be one of the best extreme pressure lubricants, the same amount of that soap in mineral oil gave results comparable to ordinary mineral oil. The effect of water is to be attributed less to cooling than to surface oxidation, in which the soap or its products of reaction may or may not take part, while effects of surface orientation and friction of the soap must be negligible. Oil acts in the parallel case as a hydrogen-producing, reducing agent, especially when present in such an excess, tending to keep the surface clean as for welding or soldering. As a matter of fact benzene is used instead of water in polishing metals to exclude oxidation. We see that in the region of wear which is our main practical concern, we are more in temperature regions of chemical bulk reactions and that the domain where orientation phenomena become of practical significance has still to be determined.

These phenomena suggest caution in the interpretation of frictional data obtained in the laboratory and in their correlation with engine experiments. They deserve attention also in the interpretation of the performance of polished surfaces because the nature of the polish, its frictional, wear and seizure properties depend on the chemical nature of the surface which will scarcely ever be a metallic surface. We clearly recognize here one very important factor of high polish: a more uniform layer of a compound interposing itself between the metal atoms of running surfaces which otherwise could approach each other to atomic distances. Such approach is, as already pointed out by Rayleigh, a prerequisite to true seizure.

SEIZURE

It is useful to distinguish clearly between various phenomena which, unfortunately, in technical literature are frequently indiscriminately called "seizure." The case silver-steel may serve for an example. It has been shown[6] that on lubricating with motor oil or petrol ether no seizure could be observed microscopically up to 30,000 lbs. per square inch with a polished steel journal. The maximum temperature attainable at peaks is the melting point of silver 961° C. At this temperature oil would decompose at the peaks and tend to reduce the oxide on the polished steel surface, thus permitting metallic contact. Silver, however, forms perceptibly neither compounds nor solid solutions with the constituents of non-alloyed steel, consequently we fail to find seizure. With alloyed steels it may be different; the constitutional diagrams of Ag with their various constituents show any possibilities. As a matter of course we can file silver by means of a steel file and thus make it even superficially stick to the roughnesses of the file. It is this phenomenon which we may observe on using a ground steel journal and its occurrence will be a matter of pressure and surface finish. The phenomenon (cold work) also appears as an increased coefficient of friction which, however, has nothing to do with the running properties of the combination silver-steel. It would be utterly misleading to call this phenomenon "seizure." A similar consideration applies to "gripping" of the journal. It is always possible to shrink a tube to a cylinder, provided the tube does not melt. This is exactly the mechanism of gripping a journal. The phenomenon leads to the emergency-running properties of bearing metals: no matter whether the bearing metal is able to combine in some manner with the journal, if its melting point is so low that at its temperature the rates of interdiffusion or combination are imperceptibly small, there can be no seizure. Entirely different as compared with silver-steel is the case copper-steel. The maximum "rubbing" temperature is 1083° C., Cu is soluble in Fe and the temperature high enough for diffusion. In this case real seizure is possible and actually occurs in practice. The only remedy against such seizure is positive separation of the surfaces which may be achieved, e.g., by nitriding the steel journal. It may be useful to add that high pressure in itself, in general, does not result in welding together of foreign metals, not even in those cases where there is mutual solubility.[13, 14]

The fundamental question of the physico-chemical running properties of a metal combination of a bearing in connection with the lubricant is always: what is the highest temperature possible and which chemical reactions may occur at this temperature, as determined by lubricant, metals and any oxidation or combustion products present? Straight mineral oil will always tend to preserve or produce clean metallic surfaces.

Electrochemical aspects of the bearing problem—A field in which the importance of additions to the oil from the point of view of surface adsorption and orientation appears somewhat neglected is protection against corrosion. We know that some of the products of oil (and fuel) oxidation are corrosive and become more so at higher temperatures with or without the aid of metal catalysts. Cylinder corrosion under starting conditions is equally familiar. The bearing corrosion problem arose in the past in connection with the cadmium-silver bearing and it may arise again in the future. The corrosion hazard is particularly great in the presence of moisture and with such bearing alloys whose components have very different galvanic potentials and do not form protective layers (e.g. of oxides) on their surfaces. Of course, there suggests itself the use of an oil which will produce such protective layers and it has been reported that in the case of certain silver-containing alloys of an oil containing sulfur performed well in the past. Many data on galvanic potentials of alloys and their constituents are available and the measurement is an easy matter. Apart from the drastic measure alluded to for the sake of completeness, we rather think of true adsorption phenomena and just want to remind the reader of the governing principle.

Polar molecules are the more preferentially adsorbed from liquid mixtures by surfaces, the more exposed their polar groups are, the positions of which appear from their chemical formulae. Practically any product of oil oxidation will be preferentially adsorbed in competition with the non-polar oil molecules. This reason would be sufficient for recommending the addition of suitable polar compounds to any mineral oil.

3. *Metallurgic questions and a new theory of bearing metals*—As many a branch of engineering and applied physical chemistry, grown on the background of an age-old craft, metallurgy was for a very long time far ahead of its scientific development. Its theoretical foundations were laid by Willard Gibbs in the late seventies in this country, developed for practical use by Bakhuis Roozeboom in the eighties in Holland, but only in the early nineties scientific metallurgic research started. No won-

der that bearing metallurgy is still in an empirical stage as far as the connection between material and use is concerned. The prototype of a bearing metal is still the hundred-year-old babbitt metal, one of those truly happy hits of craftsmanship, on the basis of which other bearing materials have been developed essentially by analogy.

FROM EXPERIENCE

Experience taught a rule with regard to bearing composition which became the leading principle to bearing metallurgists and a doctrine in engineering courses. This rule proclaims a hard and a soft constituent, i.e., structural element, the indispensable requirements for a satisfactory bearing metal. On examining actual bearing metals we find this qualitative rule confirmed. However, engineers looked for an explanation, for the working principle behind this rule. This search condensed in the following theory, in the presentation of which we follow essentially Bassett[15]: 1. No single metal or (homogeneous) solid solution will work properly; it is absolutely essential that there shall be a hard constituent, supported or embedded in a matrix of softer metal. 2. The load is carried by the hard constituent of the alloy which stands in relief above the soft matrix, the valleys thus formed serving in some degree as reservoirs for the lubricant.

Point 1 has also been stated by Bierbaum[16] and observations are quoted which are interpreted as being in support of point 2. We shall refer to them later. Point 1 must definitely be dropped. It was challenged particularly by Goodman[17] on the basis of tests on pure lead. More material in support of Goodman's findings is presented in an excellent review on automotive bearings by Underwood.[18]

As to the second point, Bassett favors the view that while the function of the hard constituent is to carry the load, the embedding soft material prevents its breakage under load. The effect on lubrication of this structure Bassett is rather inclined to ascribe to a film of the softer metal which has been dragged over the harder parts. Bassett mentions very appropriately the difficulty encountered on polishing metallographic specimens of white metal, by such dragging of the soft metal. A paper of Seyderhelm is quoted by Bassett (quotation wrong!) tending to show that with very little oil under unfavorable conditions the soft metal melts out, acting as a lubricant. We would rather prefer to consider such extreme conditions separately as "emergency running properties" of a bearing metal because they involve bulk melting. Great attention has been paid to them ("Notlaufeigenschaften") in Germany,[19, 20] particularly in connection with copper-lead and other airplane engine bearings. While Bassett comes (as we shall see presently) so close to the actual working mechanism of bearing metals, in the discussion of the individual alloys he does not maintain his objections against the orthodox bearing theory, to use an expression of Underwood, but uses it in explaining performance or failure of structures (e.g. page 252).

Now, the copper-lead bearing metal is of unusual interest. In the first place, it is not an alloy and may be considered in first approximation as composed of two pure metals, Cu and Pb. Second, with respect to its composition and structure, it is very sensitive regarding its behavior towards the journal.[19, 21] Third, copper alloys with steel; the maximum local friction temperature at a copper-steel contact is high, viz. 1083° C. (MP of Cu), so that true seizure is possible. Furthermore we know that a copper-lead bearing from whose surface the lead is extracted by corrosion will not stand the loads of a healthy bearing without scoring the journal. In fact the comparable load capacities are for good copper-lead and pure copper 470 and 180 kgs./cm² respectively.[19]. Finally, a healthy operating copper-lead bearing shows the copper color and not lead dragged across the copper.

TABLE 1

Coefficients of thermal expansion $\beta \times 10^6$ (1/degr.) and thermal conductivity λ (cal./cm. sec. degr.)

		$\beta \times 10^6$		λ
Ag	0—100°C.	**1.97**	100°	1.0
Al	0—100	**2.38**	100	0.49
Au	17—100	1.43	100	0.74
Bi	17—100	1.35	100	0.02
Cd	50	**3.1**	100	0.205
Co	50	1.24	...	....
Cu	100—300	1.64	100	0.87
Fe	25—100	1.25	100	0.1
Ir	17—100	0.66	...	....
Mo	0—100	0.52	...	....
Ni	0—100	1.3	100	0.13
Pb	17—100	**2.93**	100	0.08
Pt	50	0.9	...	....
Rh	50	0.86	...	....
Sb	17—100	1.08	100	0.04
Sn	17—100	**2.7**	100	0.14
Wo	17—100	0.34	0	0.38
Zn	17—100	1.7	100	0.26

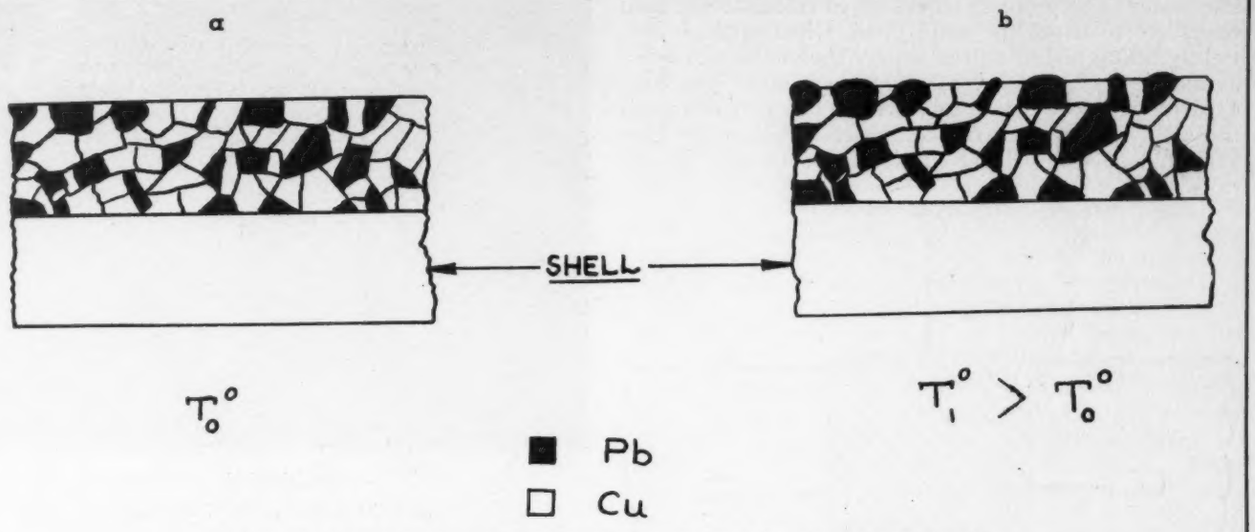
THE LOAD CARRIER

These facts show: 1. Hollows or valleys filled with oil, around the "hard" structural element cannot be substituted for the soft constituent; the latter is essential for carrying the load without damage to the journal. 2. The function of the soft element is under normal operating conditions (in contrast to "emergency conditions") not a direct lubricating effect.

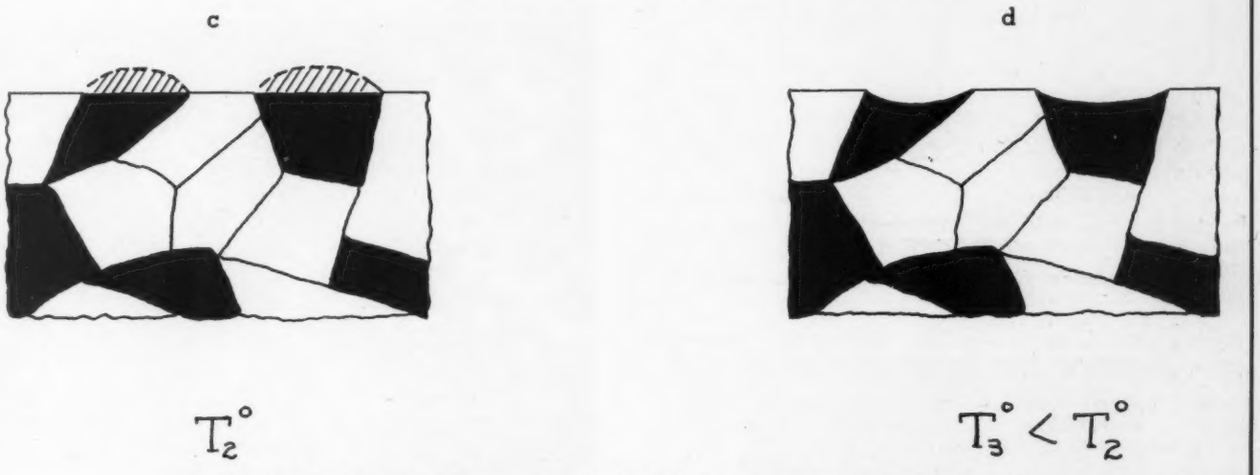
The only remaining alternative is that it is just the weak and soft constituent and not the strong one that carries the load.

It is surprising to notice that in matters of boundary lubrication layers of a few, or even one molecule thickness are often assumed to make a tremendous difference in performance, whereas the differential thermal expansion of microscopically tangible heterogeneous areas of the bearing metal has been ignored. Table 1 shows comparable coefficients of thermal expansion and thermal conductivity of the most common metals. In the case of our simple constituents we can say with reasonable approximation that the ratio Pb : Cu equals 1.8 : 1 for the thermal expansion and 1 : 10 for the thermal conductivity (which plays a part in the non-stationary state of warming up). The table shows, moreover, that the metals found by practice suitable for soft bearing constituents, and *only* these, stand out among all other metals for their high coefficients of thermal expansion, viz. Cd, Pb, Sn, Al and Ag. This shows that the combination copper-lead is not an exceptional case but just a particularly simple one of a general rule.

We can readily show that the principle of differential thermal expansion is in agreement with practical observations even in those cases which appear to support the old theory. Figure 1 (a and b) shows schematically the thermal behavior of copper-lead in operation assuming the crystallites of the components to be about of equal size. Supposing we keep the size of the Cu-crystals the same and let decrease the size of the Pb-crystals. Then, we reach a size where the volume expansion of a Cu-crystal equals or even exceeds that of a Pb-crystal. This way, the protection afforded by the principle of differential expansion—the protruding Pb-crystals—would be more or less offset. Supposing, once more, a structure of the type of Figure 1 were subjected to



Schematic representation of cut through surface of bearing metal, showing differential thermal expansion.



Detail of a and b. Protruding parts wearing off at temperature of operation (c). Relief structure after cooling (d).

FIGURE 1

excessive loads, high temperature and non-fluid lubrication, i.e., to typical heavy duty service. In this case, in time, wear is liable to occur to the lead, even if there is no actual macroscopic melting. On inspecting the cool bearing after use, we would find the "hard" constituent standing the more boldly in relief *above* the soft one, the more it had grown out before, i.e., the more severe the operating conditions have been (Figure 1, c and d). This is exactly the case described by Bierbaum.[16] Assuming a structure similar to Figure 1 and a temperature rise of 100° C., the Pb-crystals would stand 10^{-5} mms. in relief above their Cu neighbors, meaning for a lubricant of the length of lauric acid (ca. 2×10^{-6} mms.) a thermal high spot pattern of five molecules' height above the copper.*

The question arises: how can the weak lead with its low yield strength support the load? In this connection certain experiments of von Kármán occurred to the writer. Von Kármán[22] compressed marble cylinders from the top surface both laterally unsupported and laterally supported by a uniform hydrostatic pressure. Figure 2. shows the structures of two test pieces because the structural difference may become significant in further studies of our problem. The unsupported specimen shows cracks in the intercrystalline boundaries, whereas the supported specimen shows lines of intracrystalline *flow*. An analogue to our case would be a solid body with a cylindrical hole, filled with a liquid

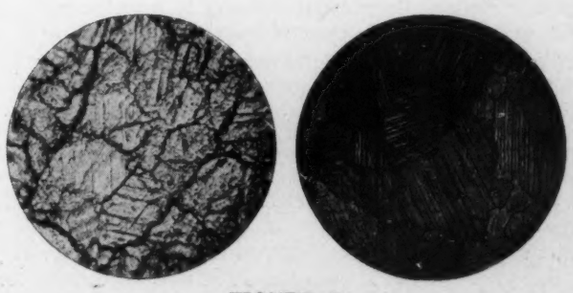


FIGURE 2

Structure of marble cylinder after compression. Left: ordinary test; right: when cylinder hydrostatically supported. (From v. Karman, ref. 22.)

*It may be mentioned that our consideration of thermal expansion might be as well based upon one observation of relief structure, provided corrosion is excluded.

like water. The problem would be to calculate the load necessary to make the solid yield, when applied to a tightly fitting piston on the water. Under the simplified assumption of a coherent copper structure the load capacity of a copper-lead mixture can be calculated from the yield strengths of the components. Following conventional notations[22] and considering a surface of one

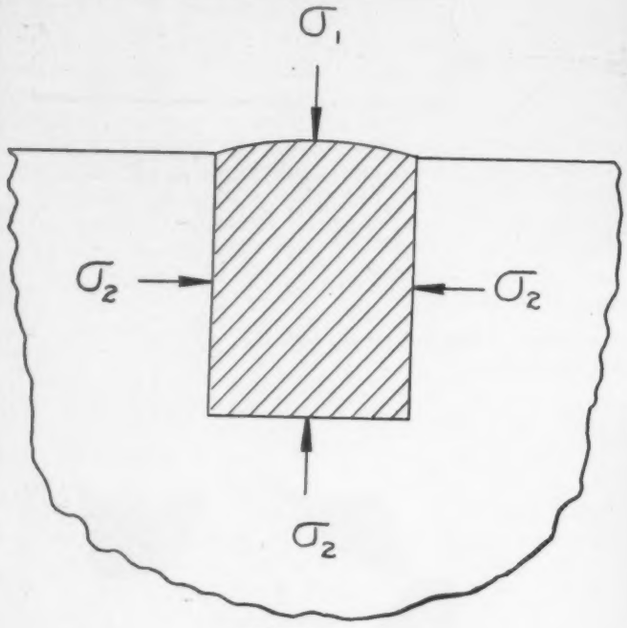


FIGURE 3
Schematic stress distribution in copper-lead structure.

square cm. (Figure 3), the difference between the principal stresses σ_1—σ_2 equals the load and we have:

$\sigma_1 - \sigma_2 =$ 100 kgs./cm.^{2} (yield strength of Pb)
$\sigma_2 =$ 2700 (yield strength of Cu[23])
hence $\sigma_1 =$ 2800 Kgs./cm.^{2}

Considering a 25 percent-lead content, i.e., only one quarter of the surface, we obtain for the load carrying capacity (yield load) 700 kgs./cm.^{2} Fischer[19] found for extremely severe conditions 470 kgs./cm^2 and for moderate conditions over 500 kgs./cm.^{2} This agreement is good in view of our simplifying, definitely favorable assumptions. Other types of structure are under investigation. A simple calculation shows as well that for a constant percentage of Pb the load capacity increases with increasing number of particles (subject to the restrictions mentioned in a preceding paragraph). In connection with particle size, suffice to mention here that the lead particles must not be so large as to permit bulging under the normal forces. It appears plausible that with the metals and temperatures concerned, the surface tension of the metal may play an important part. These questions will be treated elsewhere.

4. *Phenomena of bearing fatigue*—The principal problem of the development of bearing metals is the problem of fatigue.[21] Figure 4 to 6 show some faultless structures of bearing metals. There is an abundant literature on this subject but for its fundamentals we must rather consult literature on crystal plasticity. Within the scope of the present paper it will do to mention a few selected papers, preferring those treating the fundamental problems. McNaughtan[24] presents a very thorough study of babbitt failure, essentially based upon experience, and its mechanical interpretation, consider-

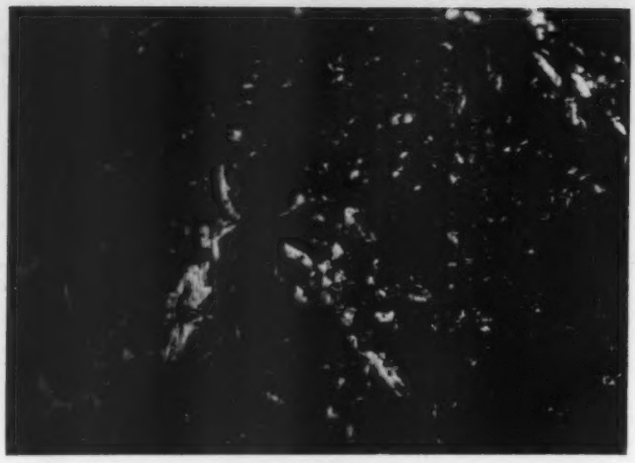


FIGURE 4
Babbitt bearing metal 330 x.

FIGURE 5
Satco bearing metal 330 x.

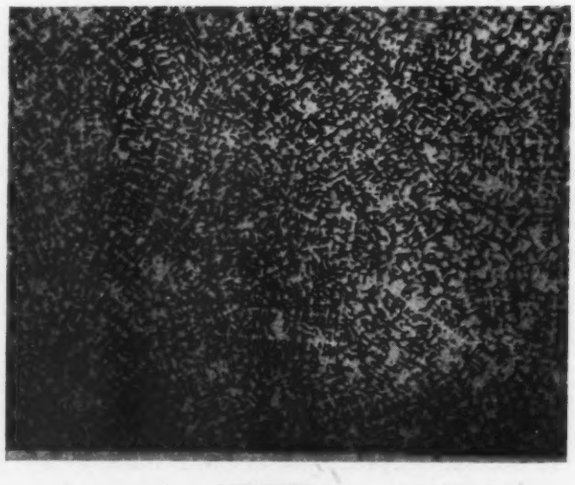


FIGURE 6
Copper-lead bearing metal 100 x.
(From Fischer, ref. 19.)

ing the stresses set up in a bearing by bonding together materials of different thermal (bulk!) expansion and emphasizing thermal stresses as a probable source of fatigue cracking. Figure 7 shows typical results of fatigue cracks on a babbitt and a satco (reinforced lead) bearing. For comparison a modern (sound) auto-

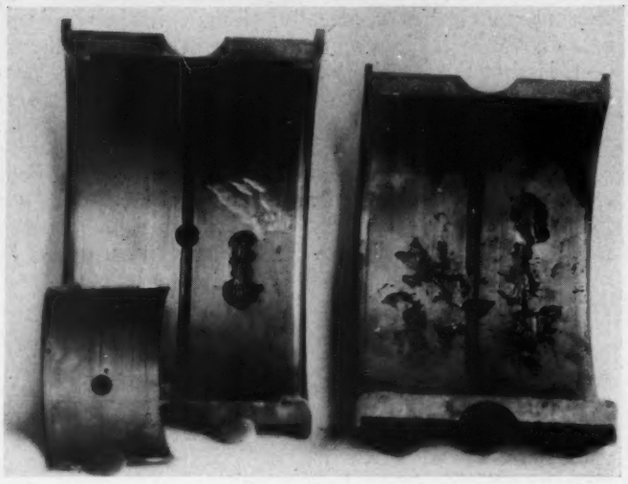


FIGURE 7

Typical bearing failures by fatigue. Left: satco; right: babbitt, 1/3 scale. Small, undamaged Cu-Pb automotive bearing.

motive copper-lead bearing is shown on this picture. This metal is also discussed by Underwood[21] and notably by Fischer[19] and Blankenfeld.[20]

DIFFERENTIAL EXPANSION

Considering the influence of the differential expansion of the microstructure, a few qualitative statements are possible on the basis of our preceding discussions. We explained the differential expansion of the soft and hard constituents and the importance of the relative grain size of the two components for the resulting volume expansion. If a structure varies considerably as to the size of its crystallites, the thermal stresses within the structure will vary considerably in the various parts of the surface and local areas, "high" due to excessive expansion or to lifting by excessively expanding neighboring crystallites, may result in local overloading of the structure and in exceeding the yield point or even break strength: the soft material of large area is strong enough to lift thermally, but too weak to support the more brittle hard constituent. A break may result, somewhat analogous to the case of unsupported marble (see Figure 2), but in this case, as always at lower temperatures with metallic materials, rather through the crystallites. We realize the importance of a structure of homogeneous size with regard to the individual constituents and of the elimination of local overheating.

A few general remarks on breaking and molecular reinforcement of crystals will be appropriate. It is pretty certain that cracking starts at cracks already present in the virgin surface or at intracrystalline irregularities. Both types of irregularities are characteristic of all *real* crystals (in contrast to *ideal* crystals). Surface scratches or holes in a crystal or casting have the same effect because of the strain concentration obtaining at such structural discontinuities (Figure 8). For more details including theoretical work on this phenomenon we refer the reader to a book by Schmid and Boas[25] and an article by W. G. Burgers and J. M. Burgers[26] as guides to the vast physical literature on the subject. The fundamental work and its stress analysis are due to Griffith.[27]

For ionic crystals (e.g. NaCl) the strength of the ideal crystal can be calculated and is about 1000 times the strength found experimentally. A discrepancy of that order is characteristic of any crystalline matter. The lattice of the real crystal may be reinforced, so that its strength comes closer to the ideal strength, in two ways: first by eliminating surface cracks (e.g. by polishing), second, by building foreign atoms into the intracrystalline defective spots. A very good review of these fundamental phenomena, with many suggestive ideas, has been given by Smekal.[28] Systematic research in this field appears promising, especially so when based upon modern conceptions of the structure of metals and alloys.[29] Thus, while impurities are almost invariably objectionable in applied chemistry and physics, in bearing metallurgy they rather improve the strength of the material, an effect the systematic study of which deserves closest attention. Because of the influence of impurities on the characteristics of crystal growth,[30] this angle of research deserves mentioning in connection with casting technique and with the well known increase of strength with decreasing crystal size of a conglomerate. With regard to thermal expansion, it is obvious that, considering fatigue, a gradual change of the coefficient of thermal expansion between two neighboring crystals is preferable to an abrupt change, i.e., a cored solid solution to a homogeneous one or to a heterogeneous conglomerate. Their relative merits as to friction are well known with the bronzes, in agreement with the theory advanced above.

FIGURE 8

Failed satco bearing showing holes from casting.

The cored structure may be prepared by melting or by compression of powders and annealing.[31, 32] Especially the latter offers promise, allowing the preparation of metal combinations which cannot be produced by melting processes, thus permitting a wider use of our fundamental expansion principle in combination with other desirable physico-chemical characteristics.

CORROSION

In conclusion we may return to two aspects of the lubrication problem in connection with fatigue. McCullough[33] directed the attention on its connection with corrosion. Such connection appears plausible in the light of Griffith's crack theory. On the other hand, Griffith[27] himself points to the analogy between the behavior of solids and thin orientated layers of liquids.

He visualizes the possibility of restoring strength to a crack to some extent by bridging it by molecules of a liquid. It might be worth while thus to attack the fatigue problem from the lubrication angle on the basis of our present-day knowledge of the connection between molecular forces and molecular structure.[3]

SUMMARY

The various physico-chemical factors are discussed, determining the behavior of bearing metals in non-fluid lubrication under the influence of local high temperatures and chemical reactions with the lubricant which are liable to occur. Journal polish is in general to be considered both as a mechanical protection against excessive cold work by greater smoothness, and as a physico-chemical protection by a protective anti-welding oxide layer. The coefficient of kinetic friction will be that of the oxidized metal.

A new theory of bearing metals is presented, explaining the mechanical part played by the various constituents of a composite bearing metal. The load-carrying capacity of a simple structure is calculated by stress analysis. The theory, derived from observation, provides a simple rule for the selection of bearing alloy components and indicates general rules for the relative particle size.

In a well composed bearing metal for high speed and temperature operation (see the excellent example discussed by Underwood, ref. 18, p. 42) it is the soft component which directly carries the load due to its higher thermal expansion. Due to the part played by volume expansion, the relative particle size of the constituents determines frictional and seizure properties. The number of metals with outstanding thermal expansion is limited to Cd, Pb, Sn, Al, and Ag. Their melting points are upper limits of "high spot" temperatures and consequently limit possible physico-chemical reactions, e.g., diffusion-seizure with the journal. Cd, Pb and Sn are for such reasons the easiest to handle. Because of their low yield and melting points their friction must necessarily be low.

Fatigue resistance and mechanical strength increase, in a general way, with the melting point. For the same reason the work of deformation increases and so does the kinetic friction—comparing e.g. Sn and Al—because there is no kinetic friction without cold work and wear. It is for this reason that any pure high-melting metal must tend to "grip" any journal under certain conditions of clearance and temperature, no matter whether this "gripping" is accompanied by true seizure (welding, diffusion) or not.

Al and Ag occupy an intermediary position between "soft" and "strong" metals. It is just this fact that recommends their use in the development of bearings of high fatigue resistance. Al is outstanding for the combination of high thermal expansion and high heat conductivity. A judicious use of these properties with due consideration of the various other factors, e.g., preservation of the natural protective oxide layer of the metal offers good promises.

Silver is the only noble metal in the series. Its chemical inertness under the conditions of bearing operation, its immiscibility with steel and its physical properties, including highest heat conductivity, are perhaps unique and render the metal nearly ideal. Good results are reported particularly in a combination with lead.[34]

It is principally with the strongest bearing metals of the series, that the question arises: pure metal or binary structure? The question is rather a question of engineering or safety and readily answered by considering thermal expansion. A binary structure, built up by an "ideal," strong, high-melting and a soft, low-melting constituent, with a surface as smooth as possible, assumes a hilly surface as the soft, highly expanding constituent grows out of the surface. This phenomenon tends to aid fluid lubrication, as visualized by the old bearing metal theory already, though for a different reason. What is, however, perhaps even more important, is that the maximum actual bearing surface, provided by the soft constituent, equals at most its percentage in the surface. In the case of the pure, strong, no matter how inert metal, contact with a much larger surface area may occur and, in this case, it happens with a *tough* material. In any attempt at reinforcing a metal by building into its lattice foreign atoms and using it in the "pure" state, its "gripping toughness" is, at least theoretically, a limit. Thus, while gripping may be prevented with a pure metal only by means of design and operation, it is strongly counteracted *structurally* in any judiciously selected binary combination. Silver is a nearly ideal structural element and the ideal bearing metal structure should be probably a Pb-Ag structure, about of the Cu-Pb type. It is well possible that fullest utilization of the principle of differential expansion may necessitate radical departures from present-day bearing manufacturing practice.

In connection with fatigue phenomena the physical fundamentals of crystal strength and Griffith's theory of rupture are briefly discussed with regard to possible effects of differential expansion on the intercrystalline stresses. The problem of intracrystalline reinforcement is briefly discussed and a possible attack of the problem of reinforcement against fatigue from the lubrication angle is suggested.

The author wishes to acknowledge advice in matters of stress analysis by Dr. Th. von Kármán, support of the work by the Rare Metals Institute and cooperation of the American Metal Bearing Company, Los Angeles.

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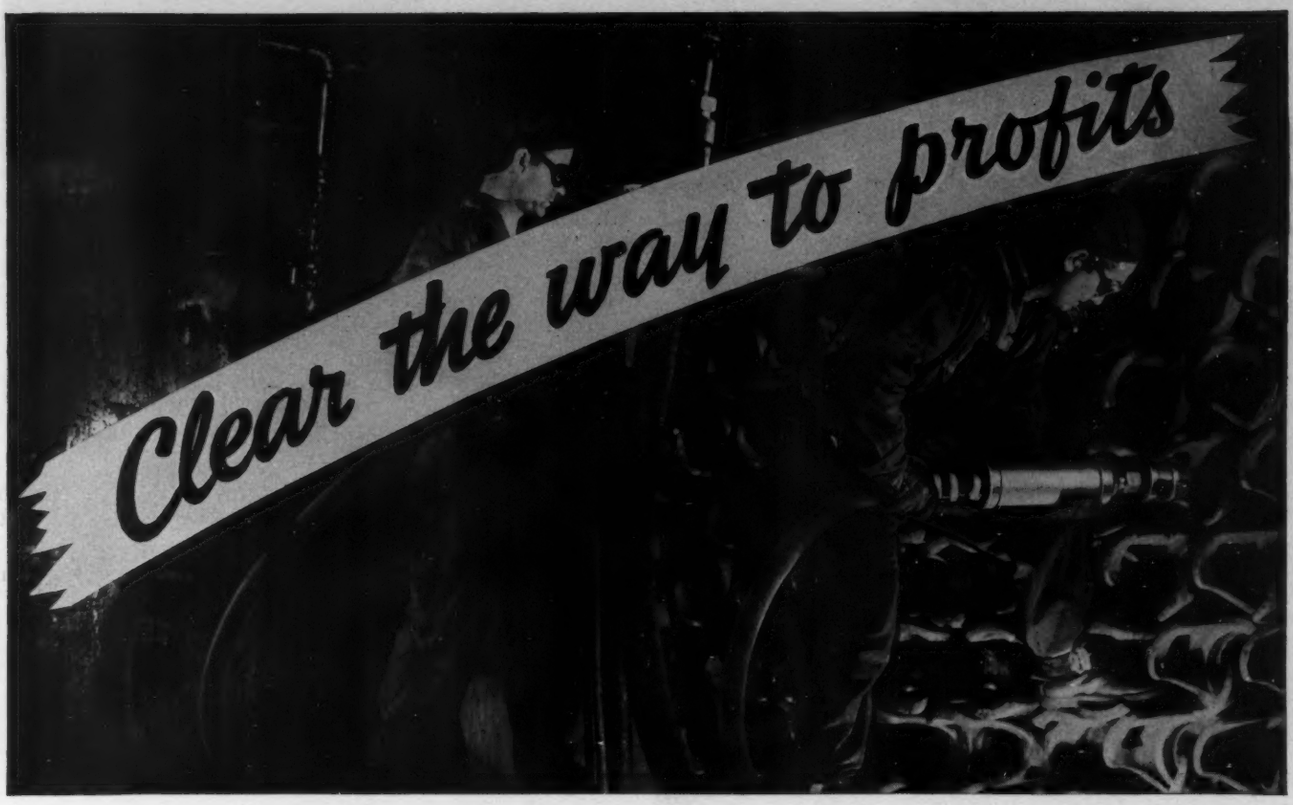

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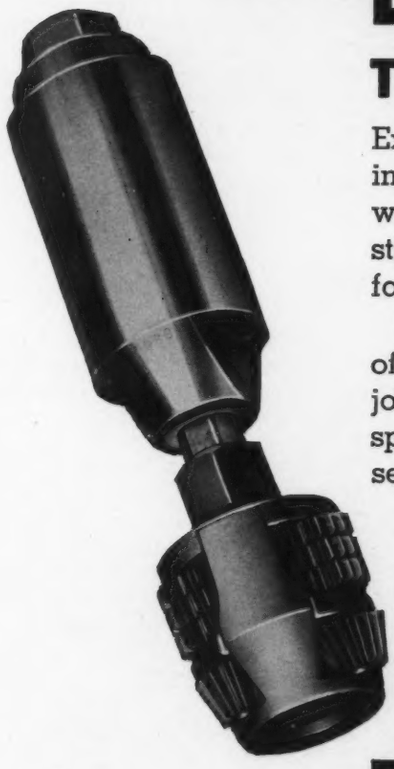

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Unprecedented Gasoline Stocks Handicap Industry

By L. J. LOGAN

SINCE the beginning of this year there has been a gradual slowing down of industrial production, from the all-time record levels that were reached in the closing months of 1939. And some fears have arisen that another important business recession may be in the making.

This clouding up of the general business situation has been accompanied by some disturbing developments within the oil industry, including the persistent weakness of the gasoline market, the recent breaking of California crude prices to somewhat lower levels, the liberalizing of crude production allowables in March in Texas, Louisiana, and New Mexico, the continued sharp rise in output of the Illinois fields, and the lagging of exports of gasoline and other oils.

Considerable doubt has been cast, therefore, upon original optimistic expectations for the oil business in 1940; and some fears have been felt that coming months might bring a spread of crude price reductions throughout the country as well as continued low gasoline prices, and that the earning power of oil companies might prove disappointing.

However, developments so far have not called for material discounting of early hopeful forecasts for the petroleum industry.

Even before 1940 arrived, it was generally foreseen by economists that the early months of the year probably would bring some cutting down of factory and mill activity, to allow orders to catch up with production. And such slowing down is what is in progress now.

So far, this deceleration has not materially affected employment or consumer purchasing power, and there have been some signs that the machinery of production may have been retarded by now about as much as will be necessary. For example, there have been increases of ordering in several lines; and the highly sensitive barometers, the stock market and the commodity markets, lately have displayed rising tendencies and thereby have seemed to promise a resumption of brisk and profitable business.

The outlook for the petroleum industry remains hopeful, therefore, in so far as favorable business in general is necessary as a background for profitable operation of oil companies.

Troubles Within Industry

Within the industry, similarly, at least some of the present retarding influences were taken into consideration in New Year forecasts, although some are proving more serious than anticipated, while several new difficulties have arisen.

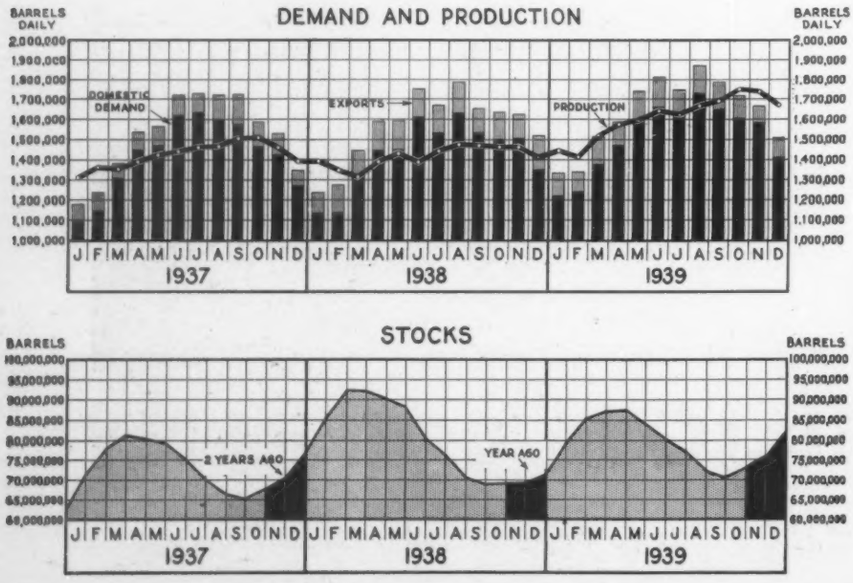
As expected, the weak gasoline market is proving to be a definite handicap, gasoline stocks having risen in recent weeks above all previous peaks. But on the other hand, as anticipated, there are compensating advantages, including larger volumes of business and good prices for refined products other than gasoline.

It was not generally foreseen, however, that the curtailment of crude production would be loosened as it has been; that exports of gasoline and some other products would shrink to the current proportions; or that extremely cold weather would accelerate the accumulation of gasoline stocks in meeting heavy demand for fuel oils. And to the extent that these difficulties have changed the picture, the outlook for the industry has been impaired.

Gasoline Situation

The depressed gasoline market, based on excessive stocks, represents the principal threat to the industry's earning power; although that barrier may prove less formidable than it now appears. Among several circumstances that could

GASOLINE SITUATION



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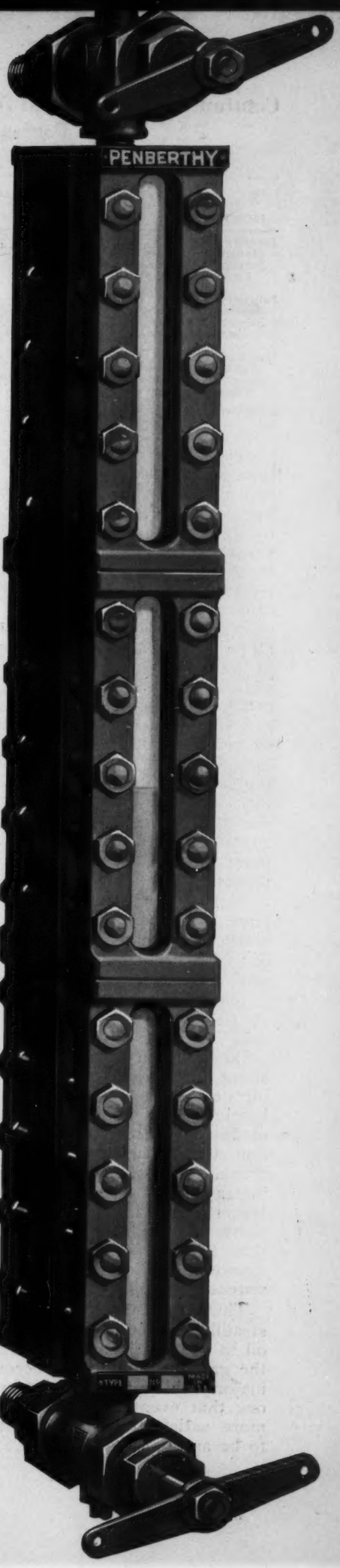

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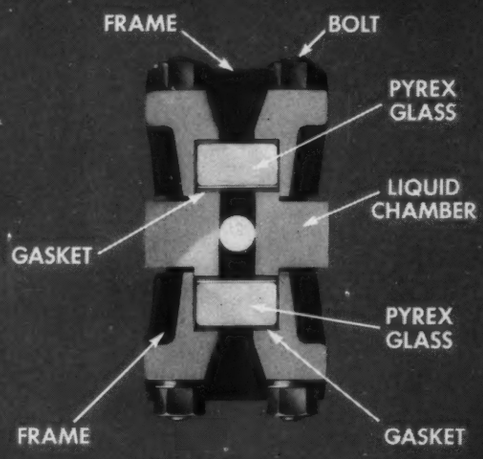

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		Domestic	Export	Total
January:				
January, 1940, forecast	110,660,000	39,500,000	3,800,000	43,300,000
January, 1939, actual	103,745,000	37,767,000	3,638,000	41,405,000
Change from year ago	+6.7%	+4.6%	+4.5%	+4.6%
February:				
February, 1940, forecast	102,340,000	37,300,000	2,800,000	40,100,000
February, 1939, actual	92,248,000	34,595,000	2,909,000	37,504,000
Change from year ago	+10.9%	+7.8%	—3.9%	+6.9%
March:				
March, 1940, forecast	108,520,000	45,100,000	3,400,000	48,500,000
March, 1939, actual	103,887,000	42,520,000	4,336,000	46,856,000
Change from year ago	+4.5%	+6.1%	—21.6%	+3.5%

result in a better gasoline market than is generally expected is the fact that American tourists have been shut off from European travel by the wars. Such tourists, diverted to travel in the United States, conceivably may swell materially the domestic consumption of gasoline.

However, gasoline stocks passed all previous peaks in the latter part of February and in early March were closely approaching 100,000,000 barrels, and a further expansion to 105,000,000 barrels or higher by March 31 was in prospect. It was indicated, therefore, that at the beginning of the spring-summer season of larger consumption, the inventory would include from 15,000,000 to 20,000,000 barrels more than the necessary working stocks.

Such a surplus obviously must have a depressing effect on the market, and material improvement of prices is not in prospect for the near future.

The surplus has been accentuated this winter by the extremely cold weather, which has forced refinery output of excess gasoline along with large quantities of fuel oil demanded by consumers for heating purposes. The industry has made some attempt to hold gasoline stocks down, by reducing the refinery yield of that product while increasing the yields of fuel oils. But there has been little appreciable success, and it is evident that such adjustments of yields cannot succeed unless applied consistently throughout the year.

This difficulty of supplying steadily increasing demand for fuel oil in winter without demoralizing the gasoline market has become a major problem for the industry and one that eventually must be met more satisfactorily if stability is to be assured.

In view of the relatively low prices that now prevail for gasoline, the industry's principal product, it logically has been questioned whether or not the refiner would be able to continue to operate on a profitable basis, while continuing to pay the established prices for crude oil.

An examination of the whole market situation has revealed, however, that the present low gasoline prices are fairly well compensated by the comparatively good prevailing prices for fuel oils, lubricants, and other products. What the refiner has lost by sagging of gasoline prices, he has largely regained by advances of other products.

The refining industry as a whole is obtaining practically as much return now from a barrel of crude as it did last November, despite a decline of about one half cent a

Demand for Oil 6.5 Percent Larger in 1939 Than in 1938

Figures indicate barrels and are from Bureau of Mines

ITEM	DECEMBER			YEAR		
	1938	1939	Percent Change	1938	1939	Percent Change
SUMMARY						
Total Demand	120,229,000	122,415,000	+ 1.8	1,330,851,000	1,417,051,000	+ 6.5
Daily average	3,878,000	3,949,000	+ 1.8	3,646,000	3,882,000	+ 6.5
Exports:						
Crude petroleum	4,883,000	4,656,000	— 4.6	77,254,000	72,073,000	— 4.6
Refined products	11,237,000	8,557,000	— 23.8	116,474,000	116,909,000	+ 0.4
Domestic Demand:						
Motor fuel	41,742,000	43,694,000	+ 4.7	523,003,000	552,557,000	+ 5.5
Kerosene	6,813,000	6,613,000	— 2.9	56,360,000	60,501,000	+ 7.3
Gas oil and distillate fuels	15,694,000	16,280,000	+ 3.6	117,449,000	131,935,000	+ 12.3
Residual fuel oils	29,746,000	30,722,000	+ 3.3	291,833,000	321,228,000	+ 10.3
Lubricants	1,831,000	1,825,000	— 0.3	21,233,000	23,613,000	+ 11.2
Wax	61,000	157,000	+157.3	995,000	1,162,000	+ 16.8
Coke	506,000	618,000	+ 22.1	5,589,000	7,110,000	+ 27.2
Asphalt	1,157,000	1,414,000	+ 22.2	24,155,000	26,879,000	+ 10.1
Road oil	148,000	71,000	— 52.0	7,847,000	7,846,000	— 0.1
Still gas	5,223,000	5,761,000	+ 10.3	65,890,000	66,979,000	+ 1.6
Miscellaneous	145,000	206,000	+ 42.1	1,776,000	2,223,000	+ 25.2
Losses	1,043,000	1,841,000	+ 76.5	20,993,000	26,036,000	+ 24.2
Total domestic demand	104,109,000	109,202,000	+ 4.9	1,137,123,000	1,228,069,000	+ 8.0
Daily average	3,358,000	3,523,000	+ 4.9	3,115,000	3,365,000	+ 8.0
TOTAL DEMAND FOR PRODUCTS						
Motor Fuel:						
Domestic	41,742,000	43,694,000	+ 4.7	523,003,000	552,557,000	+ 5.5
Exports	5,423,000	3,136,000	— 42.2	50,109,000	44,559,000	— 11.1
Total	47,165,000	46,830,000	— 0.7	573,112,000	597,116,000	+ 4.5
Aviation Gasoline:						
Domestic	*	292,000	.....	*	*	.....
Exports	*	372,000	.....	*	4,234,000	.....
Total	.....	.....	.....	.....	.....	.....
Kerosene:						
Domestic	6,813,000	6,613,000	— 2.9	56,360,000	60,501,000	+ 7.3
Exports	803,000	652,000	— 18.8	7,504,000	8,243,000	+ 9.8
Total	7,616,000	7,265,000	— 4.6	63,864,000	68,744,000	+ 7.6
Gas Oil and Distillate Fuels:						
Domestic	15,694,000	16,280,000	+ 3.7	117,449,000	131,935,000	+ 12.3
Exports	2,413,000	1,998,000	— 17.2	29,641,000	32,021,000	+ 8.0
Total	18,107,000	18,278,000	+ 0.9	147,090,000	163,956,000	+ 11.5
Residual Fuel Oils:						
Domestic	29,746,000	30,722,000	+ 3.3	291,833,000	321,228,000	+ 10.0
Exports	1,737,000	1,320,000	— 24.0	17,920,000	17,490,000	— 2.4
Total	31,483,000	32,042,000	+ 1.7	309,753,000	338,718,000	+ 9.3
Lubricants:						
Domestic	1,831,000	1,825,000	— 0.3	21,233,000	23,613,000	+ 11.2
Exports	676,000	1,310,000	+ 93.7	9,417,000	11,981,000	+ 27.2
Total	2,507,000	3,135,000	+ 21.5	30,650,000	35,594,000	+ 16.1
Wax (thousands of pounds):						
Domestic	17,063,000	43,971,000	+157.7	278,532,000	325,460,000	+ 16.8
Exports	22,311,000	14,603,000	— 34.5	201,447,000	232,664,000	+ 15.5
Total	39,374,000	58,574,000	+ 48.7	479,979,000	558,124,000	+ 16.3
Coke:						
Domestic	101,100,000	123,600,000	+ 22.2	1,117,700,000	1,422,100,000	+ 27.23
Exports	11,600,000	12,600,000	+ 8.6	155,600,000	285,800,000	+ 8.4
Total	112,700,000	136,200,000	+ 21.4	1,273,300,000	1,707,900,000	+ 34.0
Asphalt (short tons):						
Domestic	210,300,000	257,100,000	+ 22.4	4,391,700,000	4,887,000,000	+ 11.3
Exports	5,400,000	2,300,000	— 57.4	49,900,000	42,600,000	— 14.6
Total	215,700,000	259,400,000	+ 20.4	4,441,600,000	4,929,600,000	+ 11.0
Road Oil:						
Domestic	148,000	71,000	— 52.0	7,847,000	7,846,000	— 0.1
Miscellaneous:						
Domestic	145,000	206,000	+ 42.0	1,776,000	2,223,000	+ 25.1
Exports	17,000	14,000	— 17.6	112,000	123,000	+ 9.8
Total	162,000	220,000	+ 35.8	1,888,000	2,346,000	+ 24.4

* Figures not available.

MADE TO RESIST CORROSION AND ALSO WITHSTAND GREAT HEAT

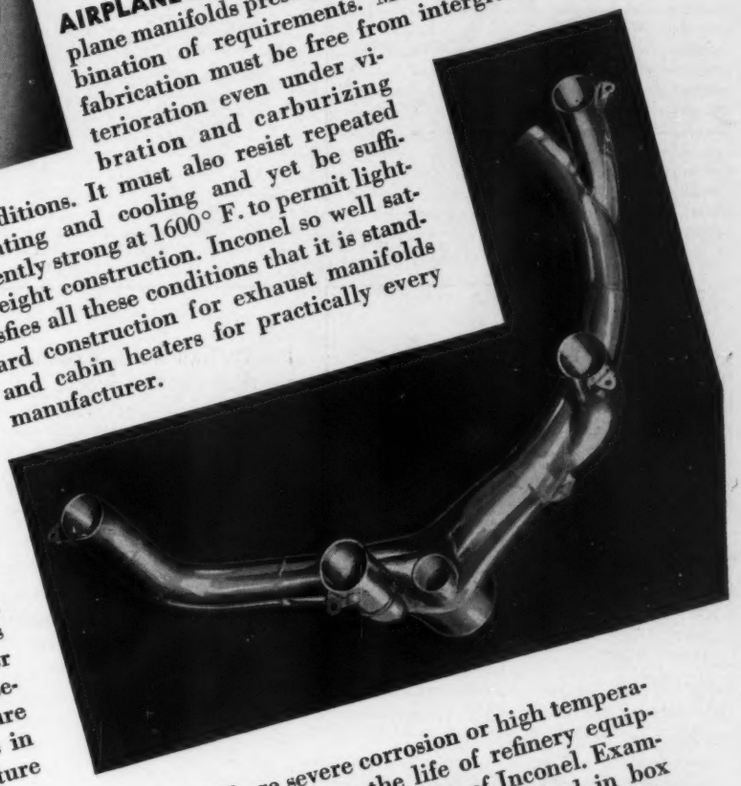
Conditions similar to those in petroleum industry successfully met by use of Inconel

REFRACTORY LINING BOLTS—Inconel bolts of special type are used to secure refractory linings on oil burning marine boilers. The heads of the bolts are subjected to temperatures as high as 2100°F. Resistance to oxidation and retention of strength are the essential properties afforded by Inconel.

• • •

VALVE SPRING—Inconel compression valve spring used on a pump handling acid mine water. Cold-drawn spring temper Inconel wire has a tensile strength of 185,000 p.s.i. Its high modulus in torsion (11,000,000 pounds per square inch) makes it a very useful material in the manufacture of springs that must operate in corrosive or high temperature applications.

AIRPLANE EXHAUST MANIFOLD—Modern airplane manifolds present an unusually severe combination of requirements. Metal used in their fabrication must be free from intergranular deterioration even under vibration and carburizing conditions. It must also resist repeated heating and cooling and yet be sufficiently strong at 1600° F. to permit lightweight construction. Inconel so well satisfies all these conditions that it is standard construction for exhaust manifolds and cabin heaters for practically every manufacturer.



Where severe corrosion or high temperatures shorten the life of refinery equipment, consider the use of Inconel. Examine its characteristics described in box (at left). Put these advantages to work in your refinery. Expert assistance from Inco Technical Service available without obligation. Write for Bulletin T-7 "Properties and Uses of Inconel" and T-8 "The Welding of Inconel and Inconel-clad Steel." Address:

THE INTERNATIONAL NICKEL COMPANY, INC.
67 Wall Street, New York, N. Y.

CHARACTERISTICS OF INCONEL

Composition: Approximately 79.5% Nickel, 13% chromium, and 6.5% iron.

Corrosion Resistance: Chromium content makes Inconel superior to pure Nickel under oxidizing conditions, keeping it bright on exposure to sulfur compounds. High Nickel content assures considerable resistance to corrosion under reducing conditions, and resistance to a wide range of neutral and alkaline salts, oxidizing acid and alkaline salts, oxidizing acids, organic acids and compounds and alkalies.

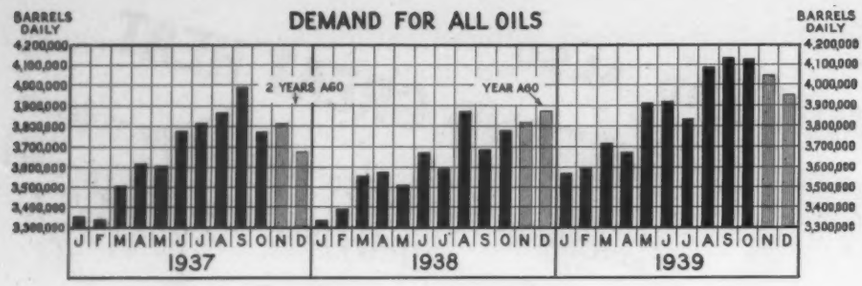
Heat Resistance: Inconel offers great strength, resistance to oxidation and freedom from intergranular deterioration at high temperatures. Short time tensile strength tests show Inconel at 1000° F. retains practically full room temperature strength.

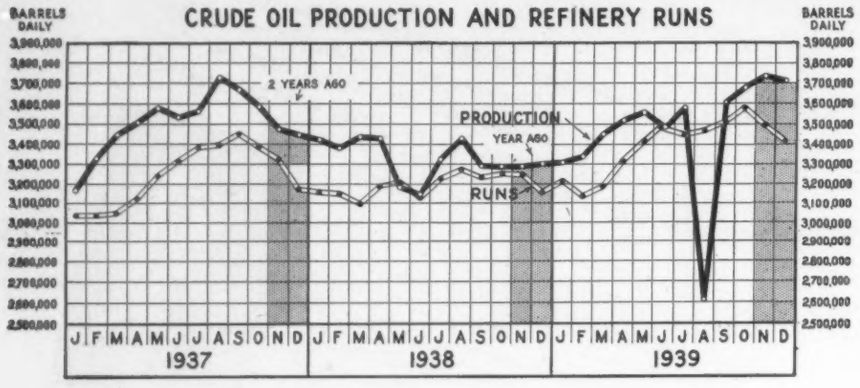
Availability: Rods, wire, sheet, strip and tubing, available from mill stocks. Inconel-clad steel plate available 3/16 in. thick and heavier.

Fabrication: Readily forged, machined, drawn, welded, cast, or formed by other metal working operations.

"Inconel" is a registered trade-mark of The International Nickel Company, Inc., which is applied to a nickel alloy containing approximately 80% nickel, with additions of chromium and iron.

INCONEL




CRUDE OIL PRODUCTION AND REFINERY RUNS
BARRELS DAILY
2 YEARS AGO
PRODUCTION
YEAR AGO
RUNS
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1937
1938
1939

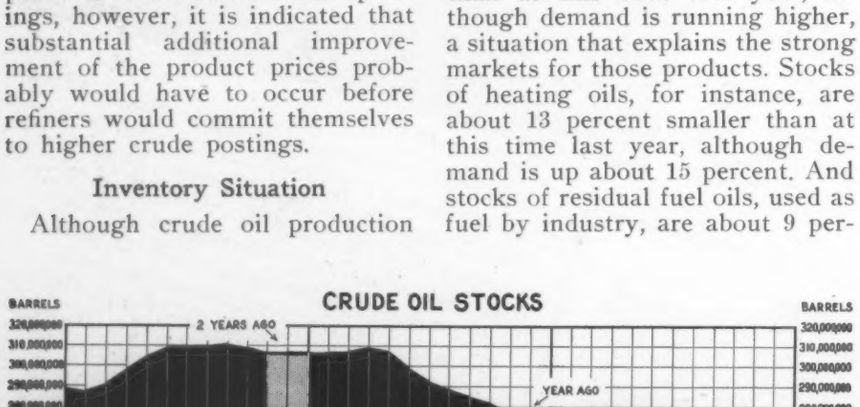
gallon in the refinery price of gasoline; and under the conditions of last fall, there was considerable talk of the possibility that purchasers might make moderate advances in their postings of prices for crude oil.

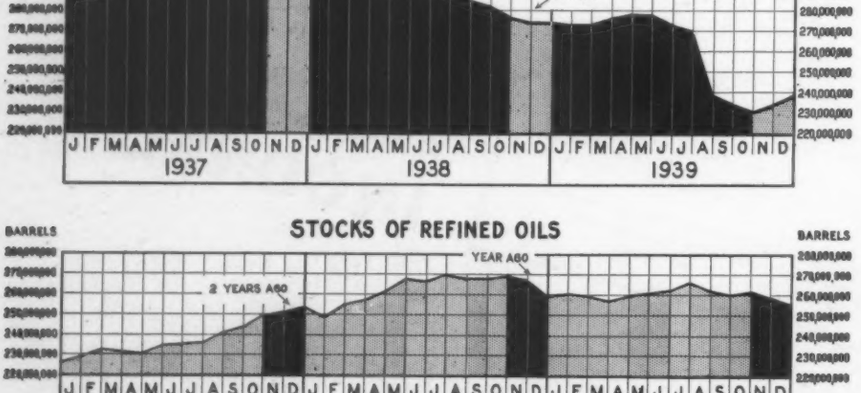
While the prices of refined products so far have given firm support for established crude postings, however, it is indicated that substantial additional improvement of the product prices probably would have to occur before refiners would commit themselves to higher crude postings.

Inventory Situation

Although crude oil production lately has been exceeding current market demand and will continue to do so under March allowables, crude stocks still are within about 10,000,000 barrels of the 17-year low level that was reached last fall.

Inventories of refined oils, except gasoline, also are moderate, being in most instances smaller than at this time last year, although demand is running higher, a situation that explains the strong markets for those products. Stocks of heating oils, for instance, are about 13 percent smaller than at this time last year, although demand is up about 15 percent. And stocks of residual fuel oils, used as fuel by industry, are about 9 percent smaller than a year ago, whereas demand has been around 10 percent larger.





Demand Outlook

Despite the fact that exports of gasoline and some other oils have been running lower this year than last year, it still is indicated that total demand will be up considerably, because of record-breaking domestic consumption. Unprecedented demand is in prospect for practically all products, including gasoline, heating oil, residual fuel oil, kerosene, lubricants, and asphalt.

Economists continue to expect another gain of about 5 percent in 1940 in the domestic consumption of gasoline, although they believe that the increase in total demand will be somewhat smaller than that percentage because of a decline in exports.

Changes from Year Ago in Stocks of Crude and Refined Oils in the United States

(Barrels of 42 U. S. Gallons)

LATEST WEEKLY DATA

(Sources: Crude stocks, Bureau of Mines; all other figures, American Petroleum Institute)

STOCKS OF:	March 4, 1939	March 2, 1940	Percent Change
Gasoline			
[1]Gas Oil & Distillate Fuels			
[1]Residual Fuel Oil			
Crude Oil	[2]271,758,000	[3]240,836,000	—11.4

LATEST MONTHLY DATA

ITEM	Stocks at End of December 1938	1939	Percent Change
SUMMARY—			
Crude Petroleum:			
Refinable in U.S.	274,958,000	238,910,000	—13.1
Heavy in Calif.	16,467,000	13,330,000	—18.8
Natural Gasoline	4,830,000	4,421,000	— 8.5
Refined Products	259,665,000	256,249,000	— 1.3
Total, all oils	555,920,000	512,910,000	— 7.7
Days' supply:			
October basis	143	130	— 9.1
12 Mo. basis	152	132	—13.1
PRODUCTS—			
Gasoline:			
Finished	65,949,000	77,301,000	+20.6
Unfinished	5,731,000	5,564,000	— 2.9
Total	71,680,000	82,865,000	+15.7
Kerosene	7,799,000	7,576,000	— 2.9
[4]Gas Oil & Distillate Fuels	27,873,000	26,374,000	— 5.4
[4]Residual Fuel Oils	97,746,000	87,774,000	— 9.2
Lubricants	7,695,000	7,142,000	— 7.2
Wax (thousands of pounds)	129,340,000	75,648,000	—42.0
Coke (short tons)	707,500,000	666,000,000	— 5.8
Asphalt (short tons)	490,400,000	550,000,000	+12.2
Road Oil	680,000	702,000	+ 3.2
Miscellaneous	263,000	276,000	+ 4.9
Other Unfinished Oils	39,233,000	36,915,000	+ 5.9

[1] At refineries only, except in California.
[2] Stocks February 25, 1939.
[3] Stocks February 24, 1940.
[4] At refineries only.

Technical Program For W. P. R. A.

TECHNICAL subjects will dominate the program of the annual meeting of Western Petroleum Refiners Association, Allis hotel, Wichita, March 31 and April 1 and 2.

This preliminary estimate of the program has been issued by John C. Day, secretary:

"Tractors are constantly being improved, which requires refiners to have available necessary fuels. Outstanding speakers have been obtained to present a paper on this subject.

"Catalytic methods of refining are attracting the attention of the industry. These methods will enable refiners to obtain higher yields and better antiknock values of gasoline. Authors have been selected who are well informed on this subject and more information will be had in the discussion which follows:

"Treating gasolines is always a problem and a paper will be presented on this subject."

Technical sessions will be held mornings and general sessions afternoons. Following the general session of the last day will come the annual election of officers and directors.

Following the convention proper an inspection will be made of the new plant of White Eagle Division, Socony-Vacuum Oil Company, Augusta, Kansas.

Gas Measurement Meeting at Norman

COMMITTEES of the Southwestern Gas Measurement Short Course, University of Oklahoma, Norman, April 16, 17 and 18, are completing work for the sixteenth annual meeting.

Fay C. Walters, Panhandle-Eastern Pipe Line Company, Kansas City, is general chairman; R. L. Rountree, United Gas Pipe Line Company, Houston, is chairman of the program committee. Other chairmen are: W. H. Carson, dean of the school of engineering, University of Oklahoma, local arrangements; Earl Kightlinger, Arkansas-Louisiana Gas Company, Shreveport, exhibits; C. A. Gibson, Cities Service Gas Company, Bartlesville, publications; R. M. Schofield, Lone Star Gas Company, Dallas, study of practical methods; Miss Kate A. Niblack, Oklahoma Utilities Association, Oklahoma City, registration and publicity.

Four additional members were added to the general committee early in 1940: E. C. McAninch, Oklahoma Natural Gas Company, Tulsa; E. L. Stark, The Foxboro Company, Dallas; C. E. Terrell, Southern Natural Gas Company, Birmingham; and W. H. Woods, Gulf Oil Corporation, Houston.

Other members of the general committee are William F. Lowe, Natural Gasoline Association of America, Tulsa; G. W. McCullough, Phillips Petroleum Company, Bartlesville; W. R. McLaughlin, Pittsburgh Equitable Meter Company, Dallas; E. M. Myers, Corporation Commission of Oklahoma; J. H. Page, Kansas Corporation Commission; E. H. Poe, Natural Gas Section, American Gas Association, New York; J. H. Satterwhite, Westcott & Greis, Tulsa; Max K. Watson, Canadian River Gas Company, Amarillo; F. M. Blair, Railroad Commission of Texas.

The Look Box

California Officials Re-elected

ALL officials of the Independent Refiners Association of California have been re-elected: DeWitt Knox, Macmillan Petroleum Company, president; R. E. Hines, Caminol Company and C. W. Allison, Triangle Oil & Refining Company, vice presidents; A. M. Lockhart, Envoy Petroleum Company, secretary-treasurer; W. S. Scully, counsel and general manager.

Promotions For Sohio Men

WITH the election of C. D. Brown, former assistant superintendent of the Toledo plant, as assistant secretary and assistant secretary of Standard Oil Company of Ohio, W. K. Bergen, process foremen at the Latonia plant went to Toledo as assistant superintendent.

Brown was at the Toledo plant during its building, which started in 1919. He was made chief clerk upon completion and became assistant superintendent.

Bergen began work at the Solar refinery at Lima while a cooperative student of Cincinnati University in 1930. He became cracking coil foreman a few months later and in 1933 was transferred to the Latonia plant in a similar capacity. He received his degree in chemical engineering while at the Latonia plant.

Conventions

MAR. 31	Western Petroleum Refiners Association, Allis Hotel, Wichita.
APR. 1– 2	Western Petroleum Refiners Association, Allis Hotel, Wichita.
8–12	American Chemical Society, Cincinnati.
16–18	Southwestern Gas Measurement Short Course, University of Oklahoma, Norman.
18–19	National Petroleum Association, Cleveland Hotel, Cleveland.
26–27	Petroleum and Natural Gas Conference, Pennsylvania State College, State College, Pennsylvania.
MAY 1– 3	Petroleum Industry Electrical Association, Dallas.
6–10	American Gas Association, Natural Gas Section, Houston.
13–15	American Institute of Chemical Engineers, Statler Hotel, Detroit.
15–17	Natural Gasoline Association of America, Hotel Tulsa, Tulsa.
18–25	International Petroleum Exposition, Tulsa.
27–31	American Petroleum Institute, Mid-Year Meeting, Blackstone and Texas Hotels, Fort Worth.

Scientists Honored At Chicago Banquet

EIGHT men whose contributions are outstanding in technical development of the refining industry were honored as "Modern Pioneers on the American Frontiers of Industry"—in Chicago February 20. The banquet was sponsored by the Illinois Manufacturers Association, Wisconsin Manufacturers Association and the National Association of Manufacturers.

Five are connected with Universal Oil Products Company, Carbon P. Dubbs, inventor of the Dubbs cracking process; Joseph G. Alther, vice president, inventor of the Equflux furnace; Dr. Gustav Egloff, director of research and holder of numerous patents; Jacques C. Morrell, associate director, also the holder of many patents; Professor V. N. Ipatieff, director of chemical research, inventor of the U. O. P. catalytic polymerization process.

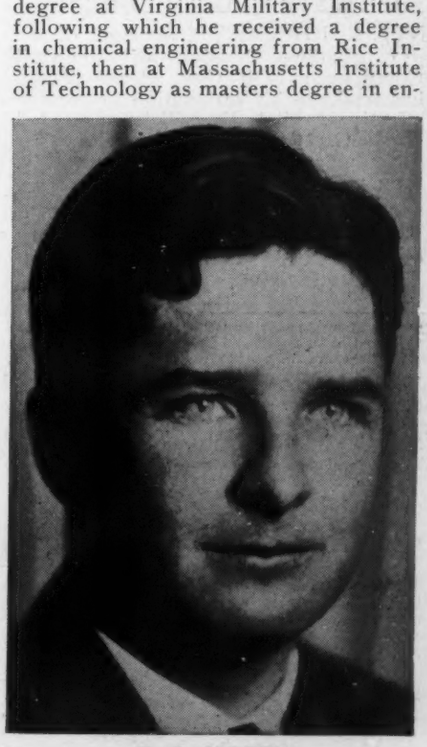
Two are with Standard Oil Company (Indiana), Dr. Thomas Hunton Rogers, associated director of research, and Dr. Vandiveer Vorhees, now a patent attorney.

Cary R. Wagner, chief chemist of The Pure Oil Company, was honored because of his work in refining technology, especially the development of thermal polymerization.

Moore Heads A.I.M.E. Petroleum Division

T. V. MOORE, Humble Oil & Refining Company, Houston, was elected chairman of the Petroleum Division of the American Institute of Mining and Metallurgical Engineers, whose annual meeting was held in New York, February 12 to 15.

Moore was born in Omaha, Nebraska, September 5, 1907. He received a B. S. degree at Virginia Military Institute, following which he received a degree in chemical engineering from Rice Institute, then at Massachusetts Institute of Technology as masters degree in en-



T. V. MOORE
A.I.M.E. Chairman

gineering. He started in the oil business with Humble Oil & Refining Company in 1929 and four years later became head of the production research department.

A prolific author of technical papers on petroleum, Moore's outstanding work in this field has been concerned with the development of mathematical formulae to determine the relationship between the rate of production of oil and gas from a reservoir and the rate of decline of the average reservoir pressure.

Moore was active in formation of the Gulf Coast chapter of A. I. M. E.

C. J. Coberly, president of Kobe, Incorporated, Huntington Park, California, was elected associate chairman of the institute's division of petroleum.

Exposition Safety Program

GOLD watches will be awarded to 12 men whose records in safety are highest in accident-free automobile and truck driving, as part of the safety program of the International Petroleum Exposition in Tulsa, May 18 to 25. The awards will be made in four divisions of the industry, refining, production, pipe lines and marketing.

Four watches will go to foremen or supervisors, one in each division, an equal number to drivers of passenger cars and four to drivers of trucks. The number of accident-free hours up to December 31, 1939, will be the basis of the award, which will be made through the safety committee of which Henry W. Boggess, Sinclair Prairie Oil Company, is chairman. The prizes will be given at the annual safety banquet.

Rules and entry blanks can be obtained from R. S. Huffman, P. O. Box 871, Tulsa.

Birkmayr Quits Pennzoil

W. R. BIRKMAYR, manager of the gasoline division of Pennzoil Company at Oil City, Pennsylvania, has tendered his resignation to become effective April 1. He will be succeeded by J. G. Miller, branch manager for the company at Erie and Union City, Pennsylvania.

Bureau of Mines Sees March Gasoline Demand

WITH gasoline stocks at an unusually high level and exports relatively low, the United States Bureau of Mines on February 21 forecast that daily average demand for domestic crude oil in March would be but 3,500,600 barrels, 28,400 barrels, or 1 percent less than the estimated demand for the current month but 4.5 percent above actual demand in March, 1939.

As a basis for its forecast, the Bureau pointed out that daily average crude production during the five weeks from January 6 to February 10 was 3,606,000 barrels, while runs to stills for the same period were but 3,471,000 barrels, resulting in an increase of 843,000 barrels in total crude stocks. During the same time, foreign stocks decreased 755,000 barrels, making the increase in domestic stocks 1,598,000 barrels, an average of 46,000 barrels a day, which, deducted from the production, leaves an indicated demand of 3,560,000 barrels daily.

Unbalanced Yields

"Relatively high runs, unbalanced yields in relation to the demand for products, and the decline in gasoline exports in the last quarter of 1939 have resulted in a material seasonal excess of gasoline stocks," the report commented. "The total stocks of finished and unfinished gasoline rose to 82,900,000 barrels on December 31, 1939, compared with 71,700,000 on December 31, 1938, an increase of 11,200,000 barrels. The relatively low distillate fuel oil stocks on January 1, 1940, east of California, combined with unusually severe weather, have contributed to higher runs to stills than were anticipated and point to a peak of finished and unfinished gasoline stocks of probably 98,000,000 barrels, or more, on March 31, 1940.

"As these additions to normal storage may represent about one-third of a possible five to six percent increase in domestic gasoline demand during 1940, their absorption involves either a postponement of the usual seasonal increase in runs, or some reduction in normal gasoline yields or both. Gasoline export trends are still materially below the high levels for the same periods of last year. The reduction of gasoline stocks will be a major problem in the second and third quarters of this year."

See Gasoline Demand Increase

The bureau foresees a domestic demand for motor fuel of 45,100,000 barrels, representing an increase of 6 percent over the actual demand of 42,520,000 barrels in March of last year. The estimate of 3,400,000 barrels for exports, however, is almost 1,000,000 barrels less than the actual shipments of 4,336,000 barrels in March, 1939.

Stocks of finished and unfinished gasoline on December 31 amounted to 82,865,000 barrels, it was pointed out, and statistics of the American Petroleum Institute indicate an increase of some 7,600,000 barrels during January, bringing them to about 90,500,000 barrels as of January 31. The bureau estimates an increase of 1,000,000 barrels in finished gasoline stocks in March, which will bring them to approximately 98,000,000 barrels by the end of next month.

Benzol and direct sales of natural gasoline are estimated at 800,000 barrels, making refinery production 48,700,000 barrels, which was allocated by the bureau among the various districts as follows:

East Coast, 6,430,000 barrels; Appalachian, 2,010,000 barrels; Indiana-Illinois, 8,930,000 barrels; Oklahoma, 2,790,000 barrels; Kansas-Missouri, 2,510,000 barrels; Inland Texas, 3,540,000 barrels; Gulf Texas, 12,480,000 barrels; Gulf Louisiana, 1,480,000 barrels; Inland Louisiana-Arkansas, 830,000 barrels; Rocky Mountain, 1,280,000 barrels; California, 6,420,000 barrels.

The report estimated natural gasoline to be blended at the refineries at 6.5 percent of the total gasoline production of 3,170,000 barrels, and the yield of straight-run and cracked gasoline at 44 percent, application of which to the production of 45,530,000 barrels of gasoline gives crude runs of 103,520,000 barrels or 3,339,400 barrels daily. Foreign crude runs are estimated at 2,200,000 barrels.

Other estimates were 5,000,000 barrels for export, a daily average of 161,000 barrels for exports compared with forecasts of 172,000 barrels for February, 185,000 for January and 194,000 for December; and 2,200,000 barrels for fuel and losses, which would make the total demand for domestic crude in March 108,520,000 barrels, or 3,500,600 barrels daily, which is allocated among the producing states as shown in the accompanying table.

Bureau of Mines Summary of Forecasts for March, 1940

	Forecast, March, 1940	Forecast, February, 1940	Actual, March, 1939
Demand for Motor Fuel:[1]			
Domestic Demand	45,100,000	37,300,000	42,520,000
Exports	3,400,000	2,800,000	4,336,000
	48,500,000	40,100,000	46,856,000
Supply of Motor Fuel:			
Straight-run and Cracked Gasoline Production	45,530,000	42,860,000	43,943,000
Natural Gasoline Used at Refineries	3,170,000	3,140,000	3,243,000
Total Refinery Production	48,700,000	46,000,000	47,186,000
Benzol and Other Natural Gasoline	800,000	900,000	1,168,000
Increase in Finished Stock	1,000,000	6,800,000	1,498,000
Available Supply	48,500,000	40,100,000	46,856,000
Crude Oil Requirements:			
Percent Yield of Gasoline from Crude	43.98	44.21	44.42
Refinery Crude Required	103,520,000	96,940,000	98,917,000
Daily Average	3,339,400	3,342,800	3,190,900
Foreign Crude Runs	2,200,000	2,100,000	2,105,000
Exports	5,000,000	5,000,000	4,966,000
Fuel and Losses	2,200,000	2,500,000	2,109,000
Total Demand for Domestic Crude	108,520,000	102,340,000	103,887,000
Daily Average	3,500,600	3,529,000	3,351,200
Increase in Domestic Stocks	.....	.....	2,881,000
Actual Production	.....	.....	106,768,000
Daily Average	.....	.....	3,444,100

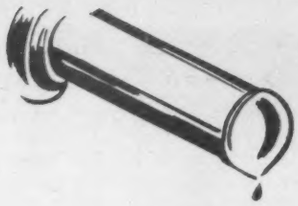
[1] The term "Motor Fuel" as used in this report includes gasoline, naphtha, and benzol used for all purposes, but does not include heavier distillates used in the operation of tractors or burned in Diesel engines.

Ark-La-Tex Meeting

MEMBERS of the Ark-La-Tex division of Western Petroleum Refiners Association heard E. L. Dennis discuss "Furnace Performances as Related to Burner Selections," at its technical meeting February 9 in Shreveport.

Liquefied Gas Bulletin

AFTER three years of committee work, the Canifornia Natural Gasoline Association has completed its new bulletin, TS-392, "Tentative Specifications and Tentative Standard Methods



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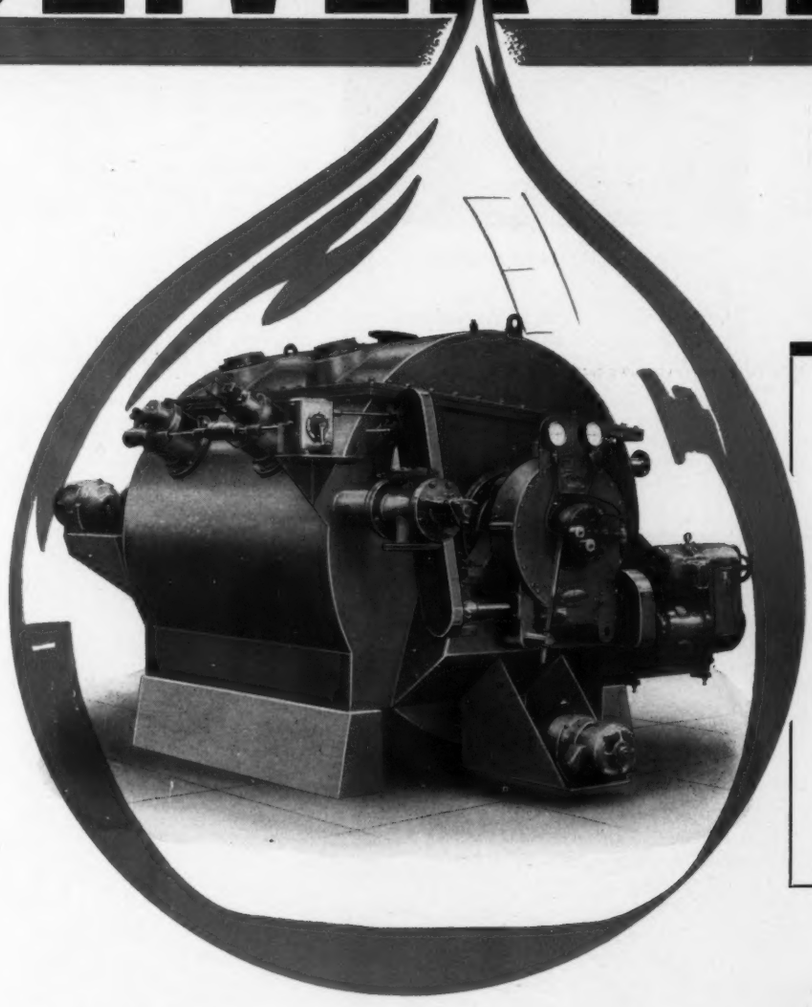

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Oliver Precoat Filtration has created an entirely new conception of filtration, particularly in connection with removing contact clays from contacted residual and overhead lube stocks . . . and without naphtha dilution. This work can now be carried on continuously and automatically. Bulletin 209 gives the details.

In addition to the Oliver Precoat Filter, other products manufactured by Oliver United Filters Inc. for the Petroleum Industry include: continuous Dewaxing Filters (vacuum or pressure); Sweetland and Kelly batch Pressure Filters; also that very excellent and durable Sweetland Metallic Filter Cloth, Style AU.

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of Test for Liquefied Petroleum Gases."

The purpose of the bulletin is to present tentative standard specifications for purchase and sale of liquefied petroleum gas mixtures varying from commercial butanes through mixtures of butanes and propane to commercial propane. It sets up six standard grades of liquefied petroleum gases in this range and presents tentative standard methods of test, setting forth procedure by which compliance with the specifications may be established.

Content of the bulletin includes specifications for the six C. N. G. A. grades; description and definition of a liquefied petroleum gas; general requirements; method of test; standard methods for determination of end-point characteristics, vapor pressure; specific gravity by pycnometer and specific gravity by hydrometer. Tables are provided of multipliers to convert volume at any temperature to volume at 60° F., physical characteristics of lighter hydrocarbons, relations between the six standards and requirements of various regulatory bodies as to minimum design pressure of containers and a vapor-pressure-conversion chart for liquefied petroleum gas.

The bulletin was compiled from the work of the association's liquefied petroleum gas committee, which is a sub committee of the technical committee. Membership of the technical committee is: John S. Gallagher, The Texas Company, chairman; F. S. Burt, General Petroleum Corporation; A. J. Bush, Tidewater Associated Oil Company; A. L. Hendrickson, O. C. Field Gasoline Corporation; Fred Hough, Southern Counties Gas Company; C. L. Hutchings, Tidewater Associated Oil Company; G. N. Hile, Standard Oil Company of California; A. N. Kerr, Imperial Gas Company; C. E. McCartney, Petrolane, Ltd.; F. O. Olmstead, Union Oil Company; C. L. Parkhill, Parkhill-Wade; Turner Smith, General Petroleum Corporation; E. J. Squire, Shell Oil Company.

JOHN S. GALLAGHER

Rice Again Heads Testing Committee

F. E. RICE, vice president, Phillips Petroleum Company, Bartlesville, has been reappointed chairman of the central committee on measuring, sampling and testing natural gas and natural gasoline of the American Petroleum Institute. This committee coordinates the work of 13 subcommittees.

Members of the central committee are: George P. Bunn, Phillips Petroleum Company, Bartlesville, vice chairman; M. J. Adams, The Texas Company, Fort Worth; W. W. Baker, Sinclair Prairie Oil Company, Tulsa; E. H. Blum, The Atlantic Refining Company, Dallas; R. R. Carney, Shell Oil Company, Tulsa; J. J. Conry, Carter Oil Company, Tulsa; J. B. Garner, Hope Natural Gas Company, Pittsburgh; R. D. Gibbs, Union Oil Company, Los Angeles; Rush Greenslade, Gulf Oil Corporation, Tulsa; R. D. Hanley, Magnolia Petroleum Company, Dallas; R. H. Hargrove, United Gas Public Service Company, Houston; Alois Kremser, Standard Oil Company of California, San Francisco; E. R. Lederer, Bradford Refining Company, Bradford.

William F. Lowe, Natural Gasoline Association of America, Tulsa; H. M. Manley, Barnsdall Oil Company, Tulsa; Ray E. Miller, Hanlon-Buchanan, Inc., Tulsa; William Moeller, Jr., Southern California Gas Company, Los Angeles; G. G. Overfell, Phillips Petroleum Company, Bartlesville; E. L. Peck, Cities Service Oil Company, Bartlesville; W. W. Robinson, The

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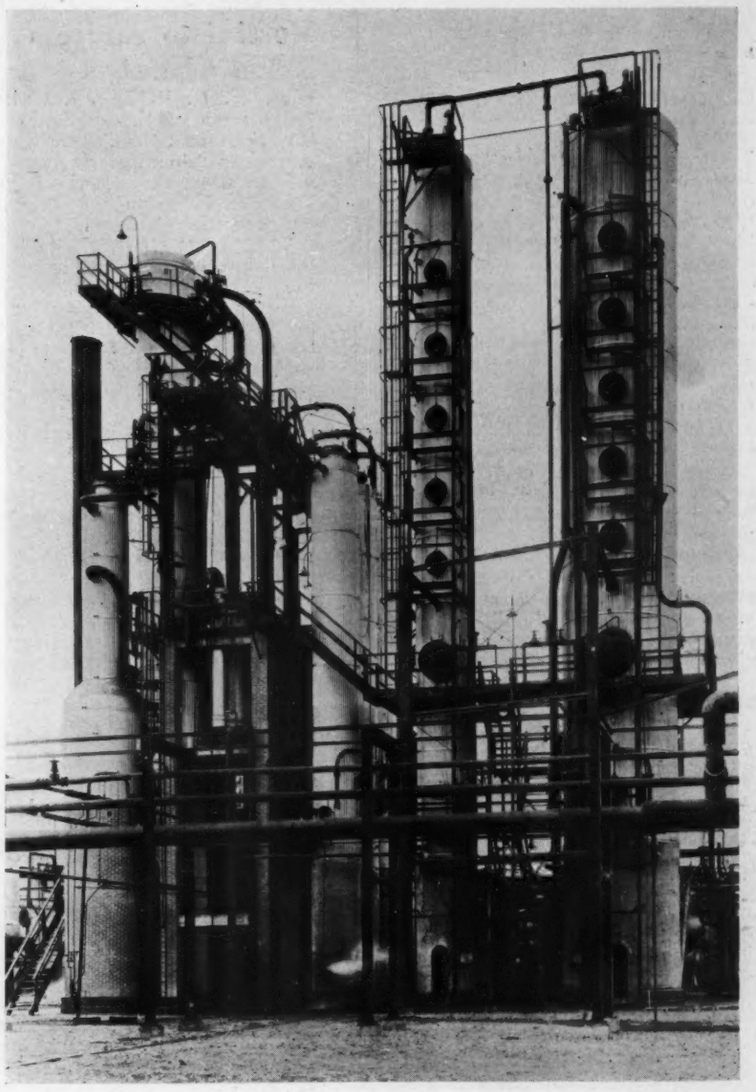

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Texas Company, Long Beach; E. F. Schmidt, Lone Star Gas Company, Dallas; F. M. Seibert, Gulf Oil Corporation, Houston; J. O. Sue, Humble Oil & Refining Company, Houston; M. N. Sweeney, Sun Oil Company, Dallas; M. E. Wagner, Ohio Oil Company, Tulsa; P. G. Weidner, Stanolind Oil & Gas Company, Tulsa; Frank Wells, Pacific Gas & Electric Company, San Francisco; C. A. Young, American Petroleum Institute, Dallas, secretary.

Chemical Contribution To Petroleum

IN accepting the Perkin Medal, awarded annually by the American Section of the Society of the Chemical Industry, Dr. Charles M. A. Stine, vice president of E. I. du Pont de Nemours & Company, pointed to the contribution of organic chemical industry to other industries and especially petroleum about which he said:

"Small amounts of a chemical such as esters and nitrilies of long-chain fatty acids increase the 'oiliness' of a lubricating oil, that is the coefficient of friction is lowered. In addition it is claimed that oiliness promoters reduce wear of moving parts, thereby minimizing shut downs and repair bills."

Dr. Stine referred to the cracking process, which while doubling the reserve of oil so far as gasoline is concerned also created a problem in that cracked gasoline had a tendency to develop gums which would lead to clogging of motor and fuel lines. Organic chemistry was credited with a substantial part in the elimination of this handicap by developing anti-ozidants such as isobutyl-para-aminophenol.

The medal was presented in New York before a joint meeting of the Society of Chemical Industry, American Chemical Society, American Institute of Chemical Engineers, the Electrochemical Society and the Societe de Chimie Industrielle.

Rossini to Address Texas Chemists

DR. F. D. ROSSINI, United States Bureau of Standards, will address the Southeast Texas Section of the American Chemical Society March 14 in the Chemistry Lecture Hall, Rice Institute, Houston, on "Chemical Constitution of Petroleum."

Open to the public, the lecture will be of interest to chemists and others in the petroleum industry. Dr. Rossini is director of the cooperative research program on the Constitution of Petroleum sponsored by the Bureau of Standards and the American Petroleum Institute. He will discuss the methods of fractionation and identification employed in the study, summarize results and outline future work.

Prior to the lecture, there will be a dinner at College Inn. Reservations should be made with the secretary.

Recently elected officers of the section are: Dr. I. S. Cliff, Shell Oil Company, chairman; Dr. F. W. Jessen, Humble Oil & Refining Company, secretary, and Dr. H. B. Weiser, Rice Institute, and Dr. G. R. Gray, Humble Oil & Refining Company, councillors.

New Officials of Lone Star Gas Company

D. A. HULCY, who has been executive vice president, was elected president of Lone Star Gas Company, following the death of L. B. Denning, February 6. The company is engaged in natural gasoline manufacture with its subsidiary, Lone Star Gasoline Company. Elmer F. Schmidt, operating manager, was elected vice president.

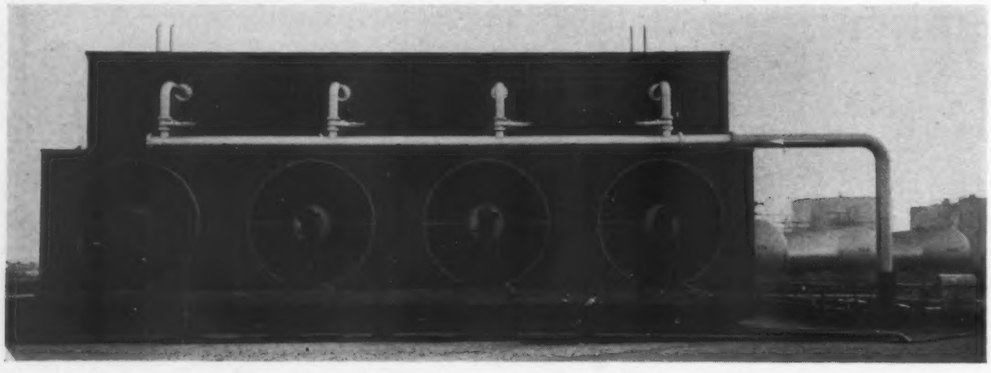
Denning was one of the founders of the company, which was the pioneer distributor of natural gas and manufacturer of natural gasoline in Texas.

Evaluation of Petroleum Products

"EVALUATION of Petroleum Products" has been published by the American Society for Testing Materials as a resume of present information on the subject. It comprises six papers originally prepared for information of members of the society's committee on petroleum products and lubricants.

Dr. J. C. Geniesse, research chemist for The Atlantic Refining Company, wrote a paper on "Lubricating Oils"; Martin B. Chittick, manager of specialty and technical sales, The Pure Oil Company, prepared a paper covering "Petroleum Lubricating Greases," while a paper on "Gasoline" was contributed by T. A. Boyd, head of the fuel department, Research Laboratories Division, General Motors Corporation.

T. B. Rendel, formerly director of



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automotive research for Shell Oil Company and now technical aviation director for Asiatic Petroleum Company, London, covered the subject of "Diesel Fuels"; H. V. Hume, superintendent of the refinery department, The Atlantic Refining Company, developed the discussion on "Fuel Oils (Other Than Diesel)," and "The Status of Research on Fuels and Lubricating Oils for Spark-Ignition Aircraft Engines" was written by S. D. Heron, research engineer for Ethyl Gasoline Corporation.

Each paper includes a number of detailed references which add to the value of the publication. Copies of the 52-page booklet can be obtained from the American Society for Testing Materials, 260 South Broad Street, Philadelphia, at 75 cents each.

Review of Cracking

A review of progress in cracking in 1938 has been published by Universal Oil Products Company, Dr. Gustav Egloff, editor, under the title "The Cracking Art in 1938."

The book of 458 pages covers catalytic cracking, midget polymerization units, isooctane units, alkylation, production of synthetic glycerole by chlorination and hydrolysis of propylene from cracked gases and hydraulic decoking of cracking still reaction chambers.

A review of patents by abstracts shows development of cracking. Statistics give a record of construction of new cracking units over the world.

Wider Vocational Training Program

AN expanded program of vocational training for the production branch of the petroleum industry has been planned for 1940 by the American Petroleum Institute's Division of Production Committee on Vocational Training. The committee recently was appointed with a substantially increased membership by W. H. Meier, Atlantic Refining Company, Dallas, who is chairman of the division's Central Committee on District Activities and of the vocational-training group.

The tentative program includes closer cooperation with the federal Office of Education and state vocational authorities who conduct the employe classes, extension of the training program to oil states which do not yet have oil-production classes, and development of a number of additional courses and texts. To provide closer contact with authorities in states which have not had petroleum courses, representation on the A.P.I. committee has been increased to include officials of nine leading oil-producing states, and the number of industry representatives also has been considerably increased.

State vocational representatives on the vocational committee are L. K. Covelle, state supervisor of Trade & Industrial Education, Stillwater, Oklahoma, vice chairman; C. A. Bell, director of vocational education, Springfield, Illinois; J. C. Beswick, chief, bureau of trade and industrial education, Sacramento, California; W. J. Breit, state supervisor, trade and industrial education, Little Rock, Arkansas; J. R. D. Eddy, state supervisor, industrial education, Austin, Texas; G. H. Fern, director, state board of control for vocational education, Lansing, Michigan; E. G. Ludtke, state supervisor, trade and industrial education, Baton Rouge, Louisiana; H. B. Northrup, director, mineral industries extension, State College, Pennsylvania; Laurence Parker, state supervisor, trade and industrial education, Pittsburgh, Kansas; and B. H. Sewell, state supervisor, trade and industrial education, Santa Fe, New Mexico.

Petroleum industry representatives are H. H. Anderson, Shell Oil Company, St. Louis, Missouri, representing the A.P.I. Committee on Public Relations; W. L. Bagby, Shell Oil Company, Ventura, California; A. H. Bell, Continental Oil Company, Los Angeles; Lot Bowen, Western Gulf Oil Company, Bakersfield, California; M. E. Brock, Gulf Oil Corporation, Houston; Geo. P. Bunn, Phillips Petroleum Company, Bartlesville; E. L. Davis, The Texas Company, Los Angeles; D. H. Fortine, Barnsdall Oil Company, Goleta, California; C. L. Hightower, United Gas Pipe Line Company, Houston; D. A. Howard, Cities Service Oil Company, Bartlesville; A. D. Jackson, Standard Oil Company of California, San Francisco; W. F. Jones, Shell Oil Company, St. Louis; J. H. Kelly, Atlantic Refining Company, Dallas; R. B. Kelly, Pure Oil Company, Olney, Illinois; J. G. Montgomery, Jr., United Natural Gas Company, Oil City, Pennsylvania; E. H. Musser, State Division

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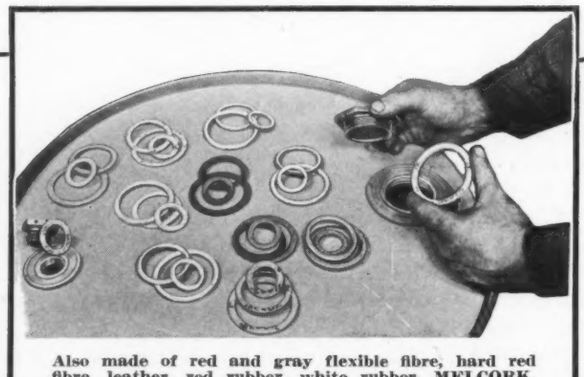

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Acetylene Association Program

LATEST practices and developments in oxy-acetylene welding and cutting will make up the program of the annual convention of the International Acetylene Association, Milwaukee, April 10, 11 and 12. Two technical sessions will be held simultaneously both April 10 and April 12 in order to allow time for the presentation of technical papers.

The first of these sessions April 10 will be devoted to papers on welding carbon-molybdenum pipe, welding industrial piping and development of silver soldering. One paper will be devoted to the layout and management of a modern welding shop. Reclamation, repair and maintenance will be the general subject of the second technical session of the first day and will also include papers on use of the oxy-acetylene process.

Round-table discussions, so popular at two previous conventions, will be held again this year on Wednesday evening at the Milwaukee Vocational School. After a short forum-demonstration meeting in the auditorium, the audience will adjourn into small groups to discuss such subjects as flame-treating, hard-facing, machine-cutting, welding alloy steels, air-acetylene applications, pipe welding, riser cutting, welding non-ferrous metals, and other subjects. Each group will have a leader who is qualified as an expert in the particular phase of the oxy-acetylene process assigned to that group for discussion.

The panel discussion on oxy-acetylene machine-cutting is scheduled for the afternoon of April 11. The subject will be discussed by a group of prominent engineers representing manufacturers and users of machine-cutting equipment. This meeting should prove to be of particular interest in view of the increasing use within the past year of the oxy-acetylene cutting machine for the fabrication of steel parts, particularly those parts which are to be subsequently welded.

The convention will close with two simultaneous technical sessions the afternoon of April 12. Foundry and heavy industry applications of the oxy-acetylene process will be under consideration at one session, with papers on such topics as flame-cleaning, dehydrating and descaling, scarfing and gouging, heavy cutting and applications of the oxygen lance, and efficiency control in oxy-acetylene cutting. The broad subject of fabrication and production has been scheduled for the second technical session. This session will be concluded with papers on the welding and brazing of light-gauge metal, including stainless steel; design and construction of jigs and fixtures for sheet metal welding; welding for enameling; welding of aluminum; and automatic bronze-welding.

Distillation Conference

REPRESENTATIVES of the licensees and owners of the Petroleum Distillation Corporation attended a technical meeting in New York February 5 and 6.

The purpose of the meeting was to discuss technical problems relating to fractional distillation of petroleum and its products and to exchange information and experience. Seven technical papers were presented and discussed. Current problems relating to fractional distillation and proposed solutions were discussed in a general round-table conference. Other meetings are planned for the future to take further advantage of experience of the membership.

A.P.I. Safety Groups Named

APPOINTMENT of the 1940 Central Committee on Accident Prevention of the American Petroleum Institute by William R. Boyd, Jr., executive vice president, and of 14 other accident-prevention committees, has been announced by H. N. Blakeslee, director of the Institute's accident-prevention department and secretary of the central committee. J. Howard Myers, The Atlantic Refining Company, Philadelphia, is chairman of the new committee.

Myers appointed committees for the following activities: awards, first aid, accident recording and reporting, purchase of safe equipment, rotary drilling, natural gasoline, pipe lines, safe handling of petroleum products, safe motor-vehicle transportation in oil fields, tank-car safety accessories, cleaning petroleum storage tanks, organization for accident-prevention, safe driving of automobiles, and safe operation of service stations.

Members of the new central committee, besides Myers, are:

J. C. Bernd, Sinclair Refining Company, East Chicago, Indiana; R. W. Black, Standard Oil Company of New Jersey, Elizabeth, New Jersey; H. W. Boggess, Sinclair Prairie Oil Company, Tulsa; J. S. Boylan, Continental Oil Company, Ponca City; A. W. Breeland, Lone Star Gas Company, Dallas; J. H. Brown, Tide Water Associated Oil Company, New York; Glenn Byers, Shell Oil Company, St. Louis; S. W. Candee, Tide Water Associated Oil Company, New York; C. W. Coleman, Gulf Oil Corporation, Port Arthur; Lee B. Conner, The Texas Company, Houston; J. H. Cuthrell, Humble Oil & Refining Company, Houston; R. J. Daugherty, Cities Service Oil Company, Bartlesville; R. E. Donovan, Standard Oil Company of California, San Francisco; H. S. Elkins, National Petroleum Association, Washington.

O. H. Gundlach, Sinclair Refining Company, New York; R. G. Guthrie, Sun Oil Company, Philadelphia; John Hammermann, Jr., Gulf Oil Corporation, Houston; Frank Harrison, The Pure Oil Company, Chicago; W. V. Hartmann, Gulf Oil Corporation, Pittsburgh; R. T. Henderson, Standard Oil Company (Ohio), Cleveland; J. E. Heston, Petroleum Advisers, Inc., New York; D. B. Hiatt, Texas Pacific Coal & Oil Company, Ft. Worth; C. L. Hightower, United Gas Pipe Line Company, Houston; J. M. Ivy, Standard Oil Company of Louisiana, Shreveport; H. W. Jackson, Kendall Refining Company, Bradford, Pennsylvania; J. H. Kelley, The Atlantic Refining Company, Dallas; W. I. Kent, Magnolia Petroleum Company, Dallas; L. F. Knox, General Petroleum Corporation, Los Angeles.

Oscar B. Lewis, Ethyl Gasoline Corporation, New York; W. F. Lowe, Natural Gasoline Association of America, Tulsa; T. S. Maffitt, Jr., Houston Oil Company of Texas, Houston; J. L. Manes, Sun Oil Company, Dallas; H. T. Markee, Phillips Petroleum Company, Bartlesville; A. J. Martinson, California Petroleum Safety Board, Los Angeles; J. D. McCamey, The Carter Oil Company, Tulsa; M. C. McDowell, Rio Bravo Oil Company, Houston; A. M. McKean, Pan American Petroleum & Transport Company, New York; F. R. McLean, Socony-Vacuum Oil Company, Detroit; R. W. Metcalf, Signal Oil & Gas Company, Los Angeles; E. D. Murphey, Mid-Continent Petroleum Corporation, Tulsa; A. A. Nicholson, The Texas Company, New York; C. J. Nohmann, Shell Oil Company, San Francisco.

A. A. Odell, Barnsdall Oil Company, Tulsa; H. S. Pettingill, Richfield Oil Corporation, New York; Geo. F. Prussing, Union Oil Company, Los Angeles; W. P. Reymond, Jr., Standard Oil Company of Louisiana, Baton Rouge; J. L. Risinger, Socony-Vacuum Oil Company, New York; R. B. Roaper, Humble Oil & Refining Company, Houston; S. D. Saltonstall, Lion Oil Refining Company, El Dorado, Arkansas; C. W. Smith, Standard Oil Company (Indiana), Chicago; J. P. Sutton, The Ohio Oil Company, Findlay; C. L. Swim, Skelly Oil Company, Tulsa; C. R. Weidner, Sinclair Refining Company, Independence, Kansas; Frank Werner, Republic Production Company, Houston; H. J. Wilson, Tide Water Associated Oil Company, San Francisco; M. K. Youker, Phillips Petroleum Company, Bartlesville.

Koch Re-named Kendall Refining Head

Otto Koch was re-elected president and treasurer of Kendall Refining Company when the company held its annual meeting last month in Bradford, Pennsylvania. Other officers named were Joseph H. Bovaird, vice president; J. B. Fisher, executive vice president and secretary; S. J. Brill, assistant treasurer and assistant secretary, and H. W. Jackson, assistant treasurer and assistant secretary.

Directors are Koch, Bovaird, Fisher, Don T. Andrus, A. E. Booth, D. W. Daily, F. D. Gallup, T. O. Grisell, Louis E. Koch, W. B. McCluer and T. P. Thompson, Jr.

▼ PLANT ACTIVITIES ▼

Polymerization at Beaumont: Magnolia Petroleum Company will install a reforming and thermal polymerization unit at its Beaumont refinery.

New Plant at Warner Alberta: Warner Oil Refining Company is constructing a 500-barrel plant at Warner, Alberta, Canada, scheduled for completion June 1.

Plant for Shelby, Montana: Production Refining Corporation has announced plans for a 500-barrel plant at Shelby, Montana. James McKay, Pittsburgh, and Phil Jacks, Beverley Hills, California, are principals of the company.

Cracking in Manitoba: North Star Oils, Ltd., St. Boniface, Manitoba, Canada, of which George Chisholm is president and T. M. Clayton is vice president and general manager, has announced an expansion program embracing installation of a 500-barrel single-coil cracking unit. Design of the unit will permit conversion to two-coil operation at a later date. The plant now skims 1200 barrels daily, drawing its supply from Turner Valley, Alberta.

Recycling at Lance Creek: A report on practicability of a co-operative recycling program for the Leo horizon of the Lance Creek field, Wyoming, will be made to operators April 1. A survey of the field was completed last month by V. C. Hendrickson, Denver.

Polymerization Unit: A thermal polymerization unit will be the chief item of expansion of the Wichita Falls plant of Continental Oil Company, where new towers, additional water cooling capacity and more pumping capacity will be added. In addition, a pipe line will be built from the K-M-A field, from which natural gasoline will be delivered to the refinery. More gasoline plant capacity will be added in the field, where a co-operative pressure maintenance and gasoline extraction plant is operated by Continental Oil Company. Total construction is to be around $750,000.

Illinois Refinery: Wood River Oil & Refining Company has been organized to start construction this month of a 7500-barrel refinery near Wood River, Illinois, at a cost of $1,500,000. Principals of the company are I. A. O'Shaughnessy, president of the Globe Oil & Refining Company, St. Paul, Minnesota; Fred Koch, of Winkler-Koch Engineering Company, Wichita, Kansas, and O. H. Ingram, of St. Paul, Minnesota. The plant, which will contain cracking equipment, is scheduled for completion in late summer. It will process Illinois crude, with the possibility that some Kansas crude may be shipped from Kansas producing properties in which the organizers are interested. Globe Oil & Refining Company operates refineries in McPherson, Kansas, and Lamont, Illinois.

Wax Plant at Titusville: Pennsylvania Refining Company is adding a wax plant and tankage to its refinery at Titusville, Pennsylvania. Work was well under way last month.

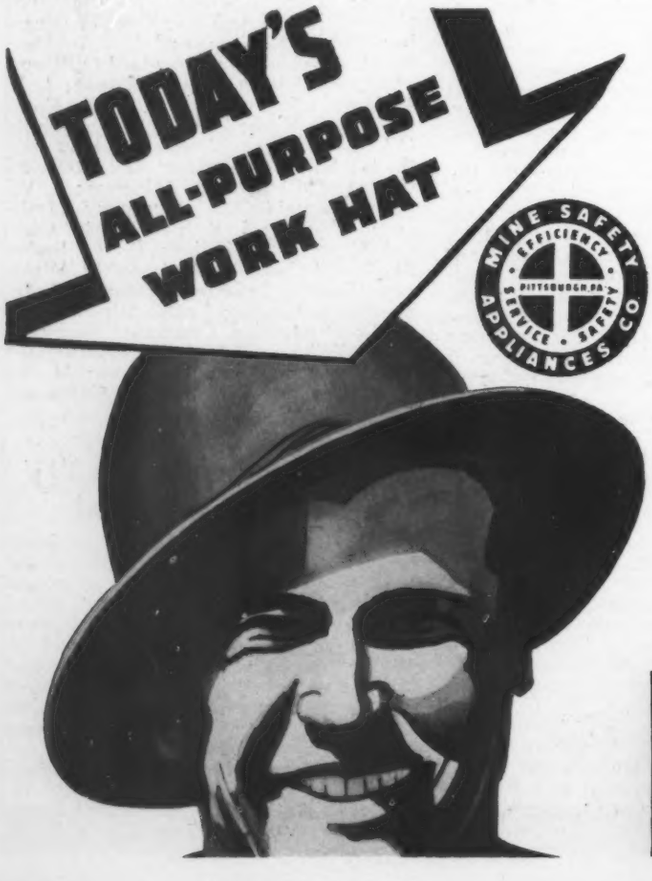
Kerosene: Northwest Refining Corpany is installing equipment for manufacture of high-grade kerosene at its plant at Cut Bank, Montana. The plant, with a capacity of 3500 barrels of oil a day, is the first in the state to install specialized kerosene manufacturing equipment.

Cracking at Bakersfield: El Tejon Oil & Refining Company, Bakersfield, California, is planning improvements in its cracking equipment. The plant, running between 2500 and 3000 barrels a day, has a viscosity-breaking unit producing 22 to 25 percent cracked gasoline.

Canadian Expansion: Gas & Oil Products, Inc., is planning installation of equipment at its plant in Calgary, Alberta, for production of high-octane aviation gasoline. The plant is now capable of producing 85-octane gasoline.

Near Completion: The refinery of A. C. Chemicals Company at Lloydminster, Saskatchewan, Canada, was nearing completion in February. Storage for 175,000 barrels of crude is being provided, and the plant will process heavy oil from the Lloydminster field into high-octane gasoline and industrial alcohol.

Junking: Dismantling of Humble Oil & Refining Company's 10,000-barrel crude skimming plant near McCamey, Texas, has been undertaken by Sampson Machine & Supply Company, Houston. The Houston firm purchased the plant on a junk basis and is salvaging



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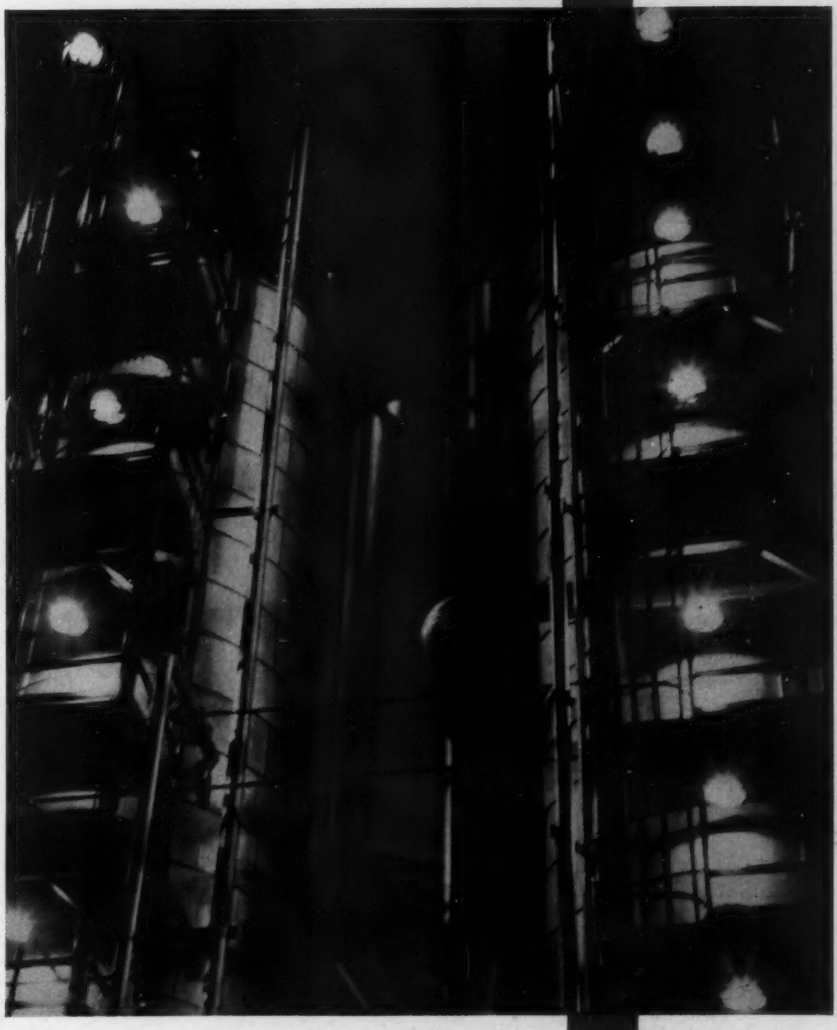

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the machinery. The remainder will be disposed of as scrap iron. The refinery was built late in 1927 to operate on surplus production held by the company. It processed crude for several years.

Drums: A new export drum and case plant has been put into operation by Republic Oil & Refining Company at its refinery at Texas City, Texas. First shipment from the plant was 35,000 drums.

Waskom Absorption Plant: Arkansas Fuel Oil Company has started operations at its new gasoline absorption plant in the Waskom field, southeast Harrison County, Texas. The unit, a high-pressure type, has a capacity of 20,000,000 cubic feet of gas daily. A recovery of 300 gallons of gasoline and naphtha is expected from each 1,000,000 cubic feet of gas. The gas, after processing, is being run into a commercial line and the gasoline is being trucked to Shreveport.

Levelland Plant Resumes: Motor Fuels Corporation's refinery at Levelland, Texas, has resumed operation under trusteeship of Ira Butler, Fort Worth attorney, appointed through voluntary court action of stockholders and creditors pending reorganization of the company.

Recycling in Nueces: Gulf Plains Corporation has let contract to Stearns-Rogers Corporation, Denver, for construction of a $2,000,000 gas recycling plant in western Nueces County, Texas. The plant will process 100,000,000 cubic feet of gas a day from the Agua Dulce and Stratton fields. The program includes drilling of 14 wells and construction of 20 miles of high-pressure gathering lines.

Recycling at Alice: W. R. Davis & Company, Houston, has awarded contract for a large recycling and natural gasoline plant to be constructed in the East Alice field of Jim Wells County, Texas, to Hudson Engineering Company, Houston. Work is to start immediately. The plant will process 60,000,000 cubic feet of gas per day to produce 50,000 or more gallons of fluid. The gas will be returned to the formation. A deal for unitization of leases in this field was recently completed.

Recycling at Long Lake: Hunt Oil Company has awarded contract for a 45,000,000-cubic-feet recycling plant in the Long Lake field, Anderson County, Texas, to Hudson Engineering Company, Houston. The plant, which will be the fourth for the field, will have 1300-horsepower compressor capacity.

Recycling at Cayuga: Roeser & Pendleton, Inc., have started construction of a gas-recycling plant for the Cayuga field, extreme northwest Anderson County. The plant, third for the field, will handle about 10,000,000 cubic feet of gas daily. The dry gas will be returned to formation. The field's first plant was constructed two years ago by Tide Water Associated Oil Company and Seaboard Oil Company, and a second plant by the two companies is now under construction.

Mexican Tetraethyl: Mexico was preparing to place in operation in early March a plant for producing tetraethyl lead. Product of the plant is to make unnecessary purchase of the product from the United States, save on foreign exchange. Mexico recently cancelled American licenses for manufacture of tetraethyl lead there.

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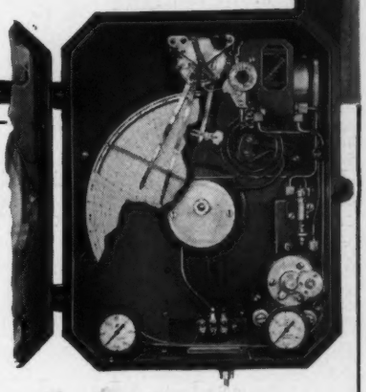

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Photostat copies of original articles will be supplied at cost by the Leslie Laboratories. Complete or limited bibliographies covering special topics by title, by abstracts, or in complete manuscript, will also be prepared and furnished at reasonable cost by the Laboratories.

Fundamental Physical and Chemical Data

Phase Equilibria in Hydrocarbon Systems, C. N. NYSEWANDER, B. H. SAGE, AND W. N. LACEY, *Ind. & Eng. Chem.* **32** (1940) pp. 118-23.

The volumetric and phase behavior of six mixtures of propane and n-butane have been investigated throughout the two-phase region at temperatures above 160°F. From these data the specific volumes and compositions of coexisting phases of the propane-n-butane system have been calculated. The experimental results are presented in tabular and graphical form. A diagram of the apparatus used in the work is given, as well as a detailed description of the apparatus.

High-Pressure Vapor-Liquid Equilibrium, E. R. GILLILAND AND H. W. SCHEELINE, *Ind. & Eng. Chem.* **32** (1940) pp. 48-54.

The investigation reported is a continuation of previous work, and covers two more systems, propylene-isobutane, and hydrogen sulfide-propane. A comparison between experimental values and those calculated from the K-charts indicate that the latter are in considerable error in the critical region. A general empirical correlation is presented for predicting phase equilibrium data for two-component hydrocarbon systems in the critical region. The data are presented in some detail in tabular and graphical form.

Tie Lines in Two-Liquid-Phase Systems, A. V. BRANCKER, T. G. HUNTER, AND A. W. NASH, *Ind. & Eng. Chem., Anal. Ed.* **12** (1940) pp. 35-7.

The article presents a method of interpolation useful in dealing in ternary liquid systems such as may be encountered in solvent extraction work or in certain types of distillation work. The literature gives many ternary systems, including one pair of nonconsulate liquids and forming two-liquid-phases with limited tie line data. In order to obtain further data without recourse to experiment, interpolation is required. This is not satisfactory using a triangular graph, but can be effected accurately by several indirect methods. Several of these are reviewed. The method described by the authors requires a knowledge of only two accurately determined tie lines.

Tie Lines in Ternary Liquid Systems, I. BACHMAN, *Ind. & Eng. Chem., Anal. Ed.* **12** (1940) pp. 38-9.

The author notes the current article by Brancker, Hunter, and Nash, in which is described a method of interpolation of tie line data requiring only two experimentally determined tie lines, and reduces tie line curves to straight lines by adopting a variably dimensioned ordinate axis based arbitrarily on Woodman's data for the toluene-acetic acid-water system. The method described by the author requires only two experimentally determined points and reduces tie-line curves to straight lines on rectangular coordinates. The method is briefly explained. It is simple and rapid. Plots for a number of ternary systems are presented in graphical form.

Viscosity Index of Lubricating Oils, E. W. DEAN, A. D. BAUER, AND J. H. BERGLUND, *Ind. & Eng. Chem.* **32** (1940) pp. 102-7.

The viscosity index scale for petroleum oils, as proposed by Dean and Davis, was based on Saybolt Universal viscosities. The constants used in making the calculations did not extend below 40 seconds Saybolt Universal viscosity at 210°F. A need exists for basic constants in kinematic as well as Saybolt units and for the extension of the scale to lower values. The present paper reports the preparation and availability of a table of kinematic constants covering the range from 2.0 to 75.0 centistokes (equivalent to 32.8-349 Saybolt seconds) at 210°F. The new table, except for a slight revision in the range corresponding to 40-50 seconds Saybolt at 210°F., is equivalent to that previously published according to the relation between kinematic and Saybolt viscosities that has been approved by the A.S.T.M. The data are presented in detail in tabular form. Nomographic charts for the estimation of viscosity indices are presented. These can be secured at cost by addressing a request to Standard Inspection Laboratory, Standard Oil Development Company, 26 Broadway, New York City.

Chemical Composition and Reactions

Preparation of Some Pure Hydrocarbons for the Purpose of Testing the Physical Methods in Use for the Examination of Hydrocarbon Mixtures, Parts 1 and 2, *Jour. Inst. Pet.* **25** (1939) pp. 801-12.

The preparation of pure, normal octadecyl benzene, octadecyl cyclohexane, octyl benzene, octyl cyclohexane, hexadecane, and hexatriacontane is described. The physical properties of these hydrocarbons are tabulated. The application of study of these hydrocarbons by the specific refraction molecular weight method for the determination of structure is considered and discussed. In the second part of the paper, the question of isomeric change in the course of the synthesis of n-octadecylcyclohexane is considered. This substance was prepared from cyclohexyl iodide and octadecyl chloride, and the hydrocarbon so made was shown to be identical with that prepared from n-octadecyl benzene by hydrogenation at 200-260°C., using high-pressure hydrogen and nickel-on-kieselguhr as a catalyst. Thus, hydrogenation under these conditions did not cause undesirable structural changes. This fact is of general interest, because similar hydrogenations are often effected in the analysis of hydrocarbon oils using the specific refraction-molecular weight method.

Properties of Wax Residues from Crude Oil, E. CASIMIR AND C. CREANGA, *Petr. Z.* **35** (1939) pp. 511-17.

The physical and chemical properties of waxes from paraffinic crude oils were investigated. They contain 77 to 96 percent hydrocarbons. The remainder is composed of resins, asphaltic materials and impurities. The hydrocarbons contain 21-48 percent higher hydrocarbons melting 91-92°C., difficultly soluble in gasoline, ether and other organic solvents, but soluble in chloroform from which it can be precipitated by absolute alcohol at 20°C. This is the fraction that forms hard ceresin. The waxes also contain 6-13 percent of solid hydrocarbons melting 57-60°C.; these compose the soft ceresin. The remaining hydrocarbons are liquid. The hard ceresin from wax residue resembles the ceresin from ozocerites in appearance, specific gravity, solubility, and absorptive properties. The analytical results are tabulated.

Combination of Saturated Hydrocarbons and Olefins. Some Problems Associated with Olefin-Isoparaffin Addition Reactions, S. F. BIRCH AND A. E. DUNSTAN, *Trans. Faraday Soc.* **35** (1939) pp. 1013-21.

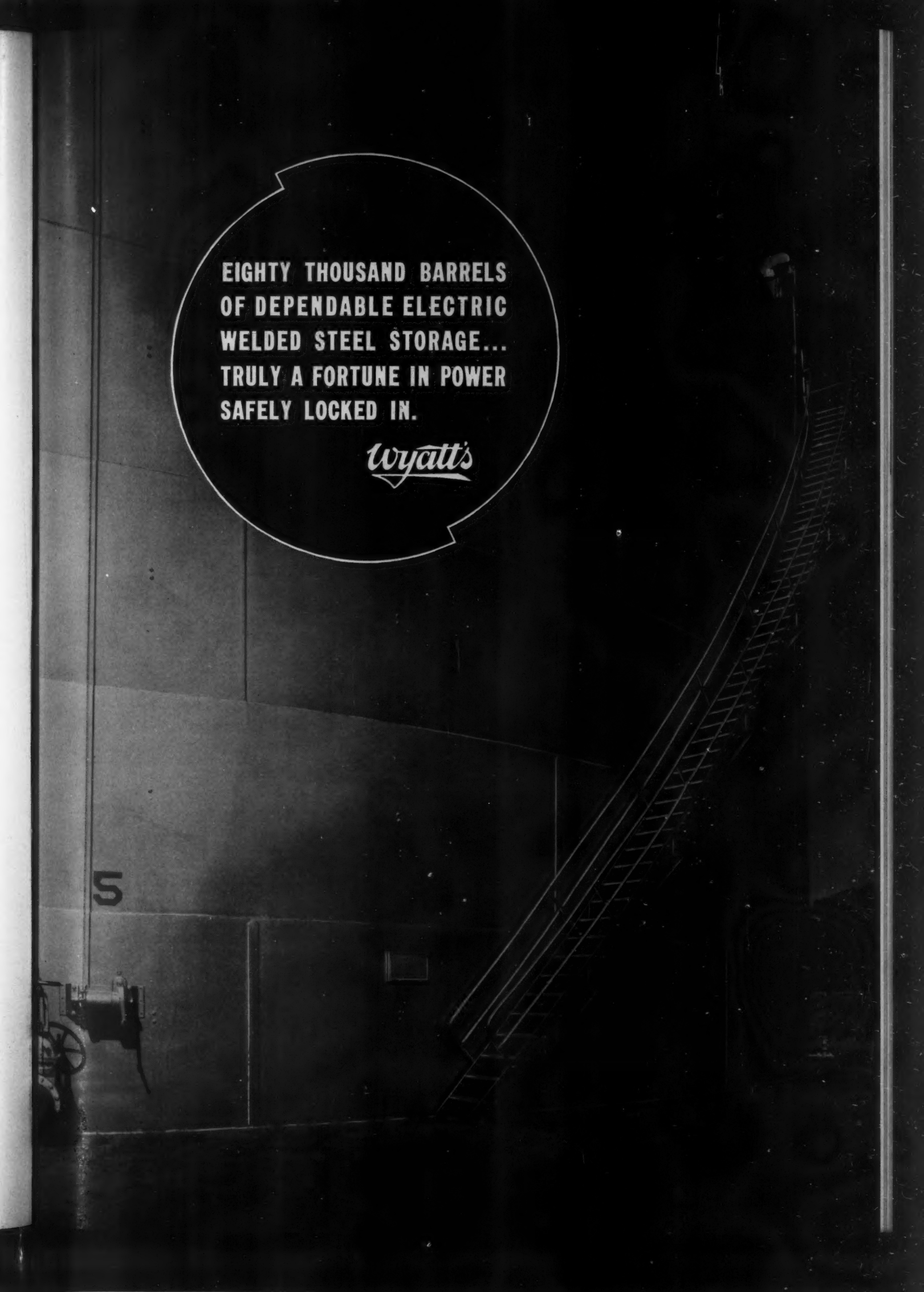
The authors discuss the addition of olefins to isoparaffins in the presence of sulfuric acid at low temperature in order to produce higher paraffins. Isobutane, isopentane, and isohexane (2-methylpentane) react readily; isooctane (2, 2, 4-trimethylpentane) does not. The olefins propene, 1-butene, 2-butene, isobutene and its di- and trimerides, the butene-isobutene codimer and trimethylene all react smoothly and give high yields of isoparaffinic products. Sulfuric acid functions as a catalyst but its activity decreases, at first slowly, and finally rapidly. The acid progressively darkens, and the volume increases. When the used acid is diluted with water a highly unsaturated oil separates. Possible reaction mechanisms are discussed.

Dimerization. Heavy Metal Sulfides as Catalysts for the Polymerization of Olefin Hydrocarbons, E. H. INGOLD AND A. WASSERMANN, *Trans. Faraday Soc.* **35** (1939) pp. 1022-4, 1052-3.

The dimerization of cyclopentadiene in paraffin solution at atmospheric pressure and 155°C. was found to occur in the presence of numerous metal sulfides. The dimerization of trimethylethylene took place most efficiently with copper sulfide prepared from cupric sulfate and H_2S in acid solution and exposed to the air until 30 percent was oxidized to cupric sulfate. Fifteen other olefins were polymerized with this CuS-$CuSO_4$ catalyst with yields varying from 3 to 45 percent. The authors suggest that the catalytic process may be an oxidation-reduction process, part of the starting substance being converted into CO_2 and H_2O, while the $CuSO_4$ is reduced to SO_2 and Cu or Cu_2O. A peroxidic intermediate compound may take part.

Dimerization of Petroleum Hydrocarbons, W. J. SPARKS, R. ROSEN, AND P. K. FROLICH, *Trans. Faraday Soc.* **35** (1939) pp. 1040-52, 1053-4.

Most of the known products from the dimerization of aliphatic unsaturated hydrocarbons can be explained by the 1, 3-rearrangement of a hydrogen atom. However, not all of the possible reaction products have been recorded, and some may not be formed. The dimerization of isobutene, the codimers of isobutene and butenes and the polymerization of the n-butenes are considered. The authors are of the opinion that the unreliability of the methods used to identify the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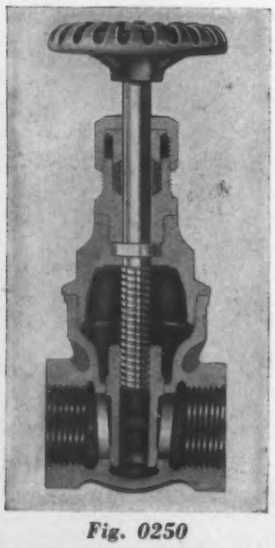

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isomers resulting from the cross-polymerization of isobutene and butene may well lead to results confusing the arguments as to the mechanism of the reactions.

Condensations by Sodium. XV. Reactions of Disodium Compounds with Ethylidene and Methylene Chlorides, A. A. MORTON AND J. T. MASSENGALE, *Jour. Am. Chem. Soc.* **62** (1940) pp. 120-3.

Ethylidene chloride reacts with amylidenedisodium to form heptene-2. Methylene chloride and ethylidene chloride react with benzylidenedisodium, yielding styrene and methylstyrene, respectively. Styrene is not obtained from the reaction of β-phenylethyl chloride with benzylsodium. Phenylsodium prepared from chlorobenzene is not as active in exchanges with toluene as is phenylsodium prepared from amylsodium. Methyl iodide and dimethyl sulfate give approximately the same yields of ethylbenzene when added to a mixture of benzylsodium and benzylidenedisodium. In neither case is the branched chain hydrocarbon, isopropylbenzene, found among the products.

Condensations by Sodium. XVI. The Formation of Decane in the Wurtz Reaction, A. A. MORTON AND G. M. RICHARDSON, *Jour. Am. Chem. Soc.* **62** (1940) pp. 123-6.

No decane is formed prior to formation of amylsodium in the reaction between amyl chloride and sodium. This Wurtz synthesis is divided into two distinct phases, one concerned with formation of the organometallic compound and the other related to reaction of this intermediate with additions of alkyl chloride. If free radicals are present in the early phase, their activity is limited to addition with sodium or to disproportionation and combination of the -idene product with two atoms of sodium to form another organometallic compound.

Catalytic Hydration of Acetylene and Some Alkylacetylenes, R. E. SCHAAD AND V. N. IPATIEFF, *Jour. Am. Chem. Soc.* **62** (1940) pp. 178-80.

The catalytic hydration of acetylene and of six alkylacetylenes was accomplished readily by passing a mixture of the hydrocarbon and steam over a solid phosphoric acid-containing catalyst under atmospheric pressure at 260-300°C. for acetylene, and at 150-204°C. for the alkylacetylenes. The different alkylacetylenes tried, both monoalkyl and dialkyl derivatives, underwent hydration to ketones. Propyne gave acetone, butyne-1 gave 2-butanone, etc.

Products: Properties and Utilization

Gum Formation in Cracked Gasolines, D. L. YABROFF AND E. L. WALTERS, *Ind. & Eng. Chem.* **32** (1940) pp. 83-8.

The usual test for the stability of gasoline comprises the measurement of the length of the induction period of the gasoline at 100°C. either in a steel bomb employing an oxygen pressure of 100 pounds, or in a granite flask with an oxygen pressure of one atmosphere. The validity of the induction period as a measure of stability has been questioned. It has been suggested that a more rational procedure would be to measure the gum contents at various periods of time when the gasolines are heated at a number of elevated temperatures and by extrapolation to obtain information on the predicted times at storage temperatures at which the gum content would reach various values. The authors were led to this same conclusion, and their present paper presents the results of preliminary work along these lines. The formation of gum during the induction period of cracked gasolines was found to proceed at a simple exponential rate at elevated temperatures. The time required for a gasoline to reach a gum content of 10 mg. per 100 ml. (designated as the 10-mg. gum time) is affected by temperature and oxygen pressure in essentially the same manner as is the induction period. The 10-mg. gum time can accordingly be extrapolated to storage conditions, which allows a prediction of the storage life of the gasoline.

Estimation of Ignition Qualities of Diesel Fuels in the Laboratory, G. VORBERG, *Oel u. Kohle* **15** (1939) pp. 497-9.

The following methods were used to obtain indications as to the ignition properties of diesel fuels: (1) hydrogen content; (2) aniline point; (3) diesel index; (4) cetene number (by Marder's density method); (5) cetene or cetane number determined by use of the I. G. or C. F. R. test-engine. The investigator's pur-

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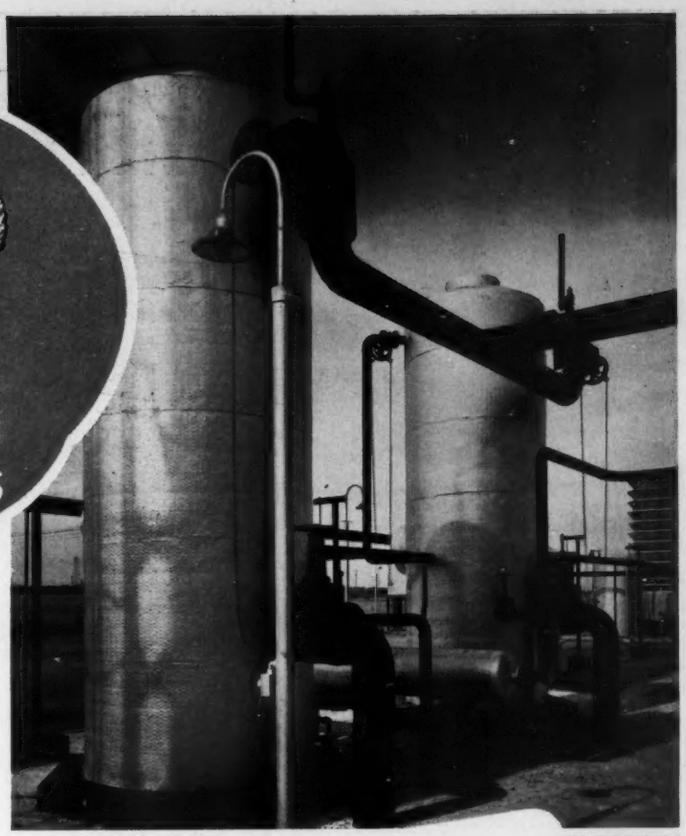

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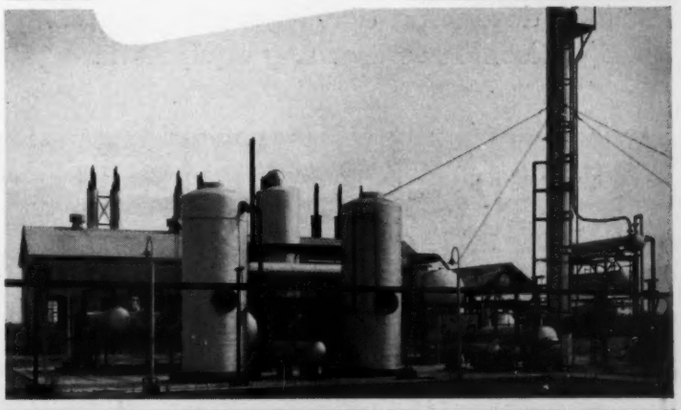

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pose was to correlate the results obtained by the first four methods with the last, which is considered the only intrinsically reliable one. Forty-two samples of widely differing origin, including oils obtained by hydrogenating coal, as well as those from petroleum, were studied. The results show that all of the methods give figures that correlate well with those obtained in the test-engine except the first method. Hydrogen content is not a reliable guide to ignition-properties. The author suggests that methods (3) and (4) are valuable for obtaining a rapid and reasonably accurate indication of the ignition properties of diesel fuels.

Piston and Piston-Ring Temperatures, P. V. KEYSER, JR., AND E. F. MILLER, *Jour. Inst. Pet.* **25** (1939) pp. 779-90.

The increase in specific power output of internal-combustion engines in recent years is responsible for a number of lubrication problems. Prominent among these is the problem of piston lubrication, which has resulted from the excessive piston temperatures in the piston-ring zone, particularly in high-speed automotive diesel engines. Piston deposits, methods of measuring piston temperature, and cylinder wall temperature measurement are discussed. The results of laboratory tests are given. Finally, the subject of the effect of design on piston temperature is considered.

Flow Characteristics of Lime-Base Greases, J. F. T. BLOTT AND D. L. SAMUEL, *Ind. & Eng. Chem.* **32** (1940) pp. 68-72.

However greases may be classified, there is no doubt that they belong to the category of plastic materials. These are bodies that may have a yield value and whose viscosities are dependent on the shearing stress applied to them. Yield value may be defined as the minimum tangential force per unit area necessary to cause flow. If a force greater than this critical value is applied, the lubricant will flow, but the rate of flow will not be directly proportional to the applied stress. When grease is applied to a bearing, it is subjected to a shearing stress that will depend on the speed or rotation and the clearances involved. Under these conditions it will flow, and its viscosity will become an important factor in the satisfactory running of the moving parts. The authors review the work done on the viscous properties of greases in recent years. They then describe an apparatus with which the absolute viscosities at 25°C. of a number of lime-base greases were determined. Mathematical expressions for the flow curves in the capillary viscometer have been evolved. These agree satisfactorily with the experimental results except in the neighborhood of the yield values. The evidence from the experiments suggests that the viscosity of the oil base is the main factor determining the viscosity of the grease at shearing stresses well removed from the yield value, and that the soap content probably controls the magnitude of the yield value.

Some Remarks Regarding the Testing of Engine Lubricants, C. A. BOUMAN, *Jour. Inst. Pet.* **25** (1939) pp. 771-8.

The author notes that the reliable judging of lubricating oils is still a source of much worry to the users of oils, to the manufacturers of engines, and to the manufacturers of oils. Also, viscosity can be measured at various temperatures simply enough, but there remains the extensive and difficult field of investigation of those properties of an oil that make it either capable or incapable of withstanding the high temperature conditions at various points in the engine. The investigation was largely concerned with this general subject. Oxidation tests do not represent the various processes of deterioration taking place in the engine; such great differences exist between processes at various points in the engine that oils are not rated in the same order of merit by this procedure. Also, deterioration of engine oil is frequently connected with contamination with combustion products, particularly in C. I.-engines. Carbon residue tests are of some value with regard to carbon formation in the combustion space, but not with regard to carbon formation in the piston-ring grooves or with respect to the tendency of the rings to stick. Engine tests are necessary, but are tedious, since the degree of reproducibility required is frequently too close to allow reaching a sound conclusion from only a few tests. Also, test conditions must be chosen so as to give a good correlation with conditions in service and use for which an oil is intended.

Extreme Pressure Lubricant Tests with Pretreated Test-Pieces, J. P. BAXTER, C. I. SNOW, AND I. T. PIERCE, *Jour. Inst. Pet.* **25** (1939) pp. 761-70.

In the course of work on the production and testing of extreme pressure lubricants,

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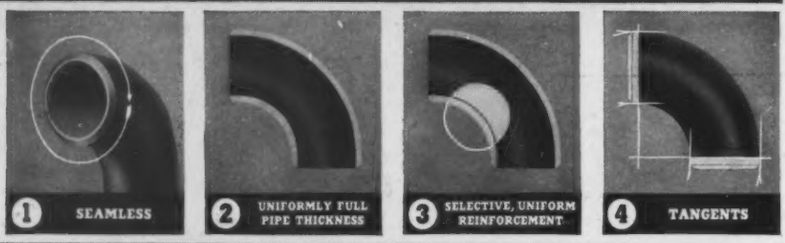

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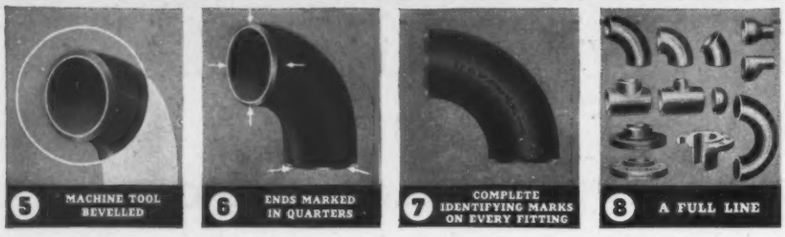

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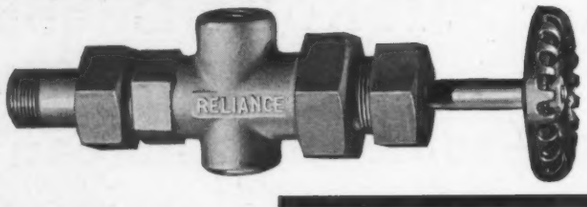

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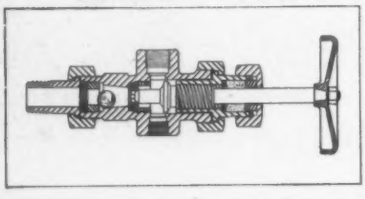

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experiments were made using three well-known lubricant-testing machines to investigate the formation of the film on bearing surfaces which is believed to underlie the phenomena of E. P. lubrication. The machines used were the Timken, the Four-Ball, and the Cornell (or Falex). When using the Timken and Four-Ball machines considerable increases in the break-down loads of the doped and undoped oils were obtained by pretreatment of the test-pieces with chlorinated or sulfurized dope or with hydrochloric acid. Running-in tests showed that the layer so formed was not removed by running under loads below the breakdown load. The pretreatment of the Cornell test-pieces had no apparent effect, but when these were hardened to a value comparable with that of the other machines, the breakdown loads became too high for the machine to measure. The formation of the layers is briefly discussed.

Effect of Sulfur and Sulfur Compounds in Naphtha upon Certain Corrosion Tests, L. M. HENDERSON, M. S. AGRUSS, AND G. W. AYERS, JR., *Ind. & Eng. Chem., Anal. Ed.* **12** (1940) pp. 1-3.

The effect of free sulfur, or sulfur compounds upon the distillation corrosion test, the copper-strip corrosion tests at 122°F. and 212°F., and the doctor test, was studied. Among the sulfur compounds used were: mercaptans, sulfides, disulfides, n-dibutyl sulfone, thiophene, and free sulfur. Naphthas from Michigan crude oil were used, including Stoddard solvent, V. M. & P. naphtha, and rubber solvent. The properties of these naphthas are given. 0.0001% free sulfur in Michigan Stoddard solvent is sufficient to affect the distillation-corrosion test. The concentration of free sulfur of 0.003 to 0.004 in Stoddard solvent just affects the copper strip used in the corrosion test at 122°F. The mercaptans, sulfides, and disulfides have no effect in the copper-strip test. The sensitivity of the doctor test was determined. A table is given showing the minimum percent by weight of mercaptan sulfur in the different mercaptans that will give a positive doctor test.

Determination of Sulfur in Organic Compounds, E. W. D. HUFFMAN, *Ind. & Eng. Chem., Anal. Ed.* **12** (1940) pp. 53-8.

A new method for the determination of sulfur in organic compounds is described and the inherent errors are discussed. The method applies to compounds containing no other elements than carbon, hydrogen, nitrogen, sulfur, and oxygen. The method comprises two procedures: (1) a reaction between the oxides of sulfur, formed during a catalytic combustion, and metallic silver with the quantitative formation of silver sulfate; (2) the electrodeposition of the silver from the silver sulfate. The plating is done in dilute isopropyl alcohol solution. Carbon-hydrogen values can be obtained simultaneously. The method and the apparatus are described in some detail, and typical results are given in tabular form. Excellent agreement between actual results and theoretical results is shown.

Manufacturing: Processes and Plant

Separation Processes, M. RANDALL AND B. LONGTIN, *Ind. & Eng. Chem.* **32** (1940) pp. 125-9.

To obtain the highest thermodynamic efficiency in a separation process, those streams that must be mixed should be potentially as nearly at equilibrium as possible. This principle is illustrated by application of graphical methods to the study of cases in which the principle is not followed. A number of faulty types of interconnection of separation units frequently found in existing industrial separation processes are pointed out. Application of the principle allows ready detection and elimination of such faulty connections, and permits a process to be easily reduced to the simplest and most effective form.

Heat Transfer in the Radiant Section of Petroleum Heaters, W. E. LOBO AND J. E. EVANS, *Trans. Am. Inst. Chem. Engrs.* **35** (1939) pp. 743-78.

The empirical equations for predicting heat transfer in the combustion chambers of steam boilers and pipestill furnaces are followed by a study of 85 performance tests on 19 furnaces differing widely in the extent and arrangement of cold and refractory surfaces. Furnaces with and without air preheat, with and without flue-gas recirculation, and fired with refinery cracked gas or oil fuel, were considered. A wide range of variation in excess air existed in different tests. The data were correlated by means of a theoretical equation. The deviations are no larger than

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the probable errors in the test data. In order to simplify the calculation the equation is presented in graphical form. The authors include an illustrative design problem.

Refinery Gas: A Raw Material of Growing Importance, R. E. WILSON, *Chem. & Ind.* **58** (1939) pp. 1095-1101.

The history of the utilization of refinery gas is briefly reviewed. The origin of these gases and their composition is considered. Gas from cracking today amounts to 7 to 8 percent by weight of the total crude oil run in the United States. This is equivalent to about nine hundred and forty million cubic feet per day, or 14 million tons per year. Uses of this gas fall into three general categories, each of which is discussed: (1) direct utilization of compounds separated from refinery gas; (2) as a raw material for the chemical industry; (3) conversion into motor fuel and other products primarily useful within the petroleum industry. One company is making commercially more than 100 synthetic chemicals, starting from ethylene, propylene, and the butylenes, including at least 24 alcohols and alcohol ethers, 4 ketones, 23 esters, 14 amines, 8 ethers, 7 chlorinated compounds, and many others. The article is an excellent review of the entire subject of the utilization of refinery gases. It is concluded with a brief discussion of the economics of hydrocarbon gases as raw materials.

Cracking Tars and Distillates from Coal, G. EGLOFF, J. C. MORRELL, G. B. ZIMMERMAN, AND W. E. LEMEN, *Ind. & Eng. Chem.* **32** (1940) pp. 39-47.

Coal tars and distillates from them can be cracked under proper conditions to produce gasoline, gas, and coke or fuel oil residues. Low-boiling phenols can be made from high boiling tar acids. The quantity of tar acids made from any coal tar fraction can be varied within limits by changing the boiling range of the entire distillate from the cracking unit. Corrosion of the equipment is more of a problem than when cracking petroleum. The plant capacity is lower in comparison. Somewhat higher gasoline and gas yields are obtained than would be expected, based on the specific gravity of the cracking stocks. The gasoline has a good antiknock value. The gas is lower in molecular weight and heating value than that from petroleum cracking. Useful quantities of higher olefins can be made from it by fractionation.

Studies of Carbon Black. V. The Effect of Gas Composition on the Production and Properties of Carbon Obtained by Non-Impingement (Lampblack) Methods, L. M. PIDGEON, *Can. J. Res.* **17** (1939) p. 353.

Lampblack is the form of carbon produced in the free flame of a burning hydrocarbon. Carbon black is formed when the free flame impinges on a relatively cool surface. Carbon black dispersed in vulcanized rubber reinforces its tensile strength and abrasion resistance, whereas lampblack does not do this. It is believed that it is largely a question of particle size. The investigation reported bears directly on the problem of whether the difference in particle size is the result of the hydrocarbon used or the method of production of the black. It was found that olefinic gases yield a lampblack that is analogous to carbon black in its action on rubber. Experiments were conducted with various hydrocarbons, and are described. It is suggested that the addition of acetylene to paraffin may produce by lampblack methods a carbon of properties identical with those of carbon black. The advantage would be higher yields and simpler apparatus.

Chem. & Met. Report on Plant Lighting, Series A, No. 1, *Chem. & Met. Engr.* **47** (1940) pp. 25-32.

The report is an engineering study of the important plant function of lighting. Although the report was made with particular reference to chemical plants, it is equally useful for refineries and other types of plants. The hazardous locations requiring special lighting equipment have been classified, and explosion and dust-tight fixtures are discussed. Attention is called to the precautions governing the use of portable lamps. The fire hazard properties of certain flammable liquids and gases, as well as volatile solids, have been correlated. The report covers the special lamps and equipment required for applications where high external temperatures prevail, where there is excessive vibration, where the service is too rough for the standard incandescent lamp, and for indicators on remote control systems. The use of fluorescent, polarized and ultra violet light sources as tools for inspection and other purposes in the process industries is considered. A specialized lighting problem discussed in the report is the prevention of sabotage in plant yards.

Flying is a complicated business, with no room for anyone but the expert . . . but for that matter, so is the business of refining gasolines and oils.

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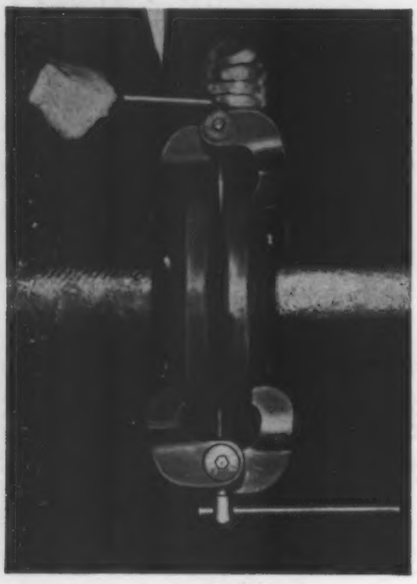
In operation, two bolts are removed from the flanges on opposite sides from each other. The jaws of a jack are placed in each of the bolt holes and tightened just enough to hold the jacks in position. The remainder of the bolts are then removed from the joint and the jackscrews tightened until sufficient opening between the flanges has been obtained. The old gasket is then removed, faces of the flanges cleaned and the new gaskets inserted. Both jackscrews are backed off simultaneously and the bolts applied to the flanges.



Garlock Flange-Jack

Gasoline and Oil Meter

SMITH METER COMPANY

A new gasoline and oil meter, Model S-12, for refinery, pipe lines, bulk plant loading racks and similar services, has been announced by Smith Meter Company, 2014 Superior Avenue, Cleveland.

The meter has 2-inch flanged connections in line for convenient bolting into the pipe line and is built for 125-pound pressure. With a sustained capacity rating of 120 gallons per minute, it is described by the manufacturer as having a hair-line accuracy that can be regulated to micrometer dimensions by a new built-in calibrator. Pressure loss through the meter is said to be less than the loss through two pipe elbows of same size as the meter connections.

Fillet-Weld Gage

GENERAL ELECTRIC COMPANY

A new low-priced fillet-weld gage has been announced by General Electric Company, Schenectady, New York, to provide a fast, accurate means of checking the size of fillet welds on jobs that must meet rigid specifications. The new device, which slides readily into a shirt or trouser pocket and is of simple construction, consists of three stainless-steel stampings held together by a bolt and a knurled thumb-nut. Either convex, concave or standard fillets can be checked merely by fitting the edge of the gage flush against the work so that the indicating portion of the gage rests on the weld bead.

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MERCO NORDSTROM VALVE COMPANY

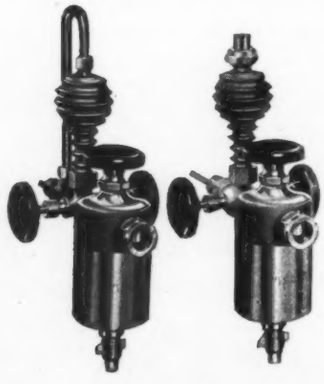
To provide a leakproof gauge cock that can be completely opened or closed with a ¼-turn, Merco Nordstrom Valve Company, 400 Lexington Avenue, Pittsburgh, Pennsylvania, have developed a lubricated type for test pressures to 4000 pounds. The cock has a rated working pressure for water, oil and gas of 2000 pounds. Its body is forged steel and it has a stainless steel plug. Stick lubricant is inserted under a lubricant screw which can be turned down. Turning of the screw transmits hydraulic pressure to the seat, and in the event the cock becomes hard to turn, the pressure exerted will loosen it. Special lubricants are available for steam. It is made in ¼-inch and ⅜-inch sizes and is wrench-operated.

Merco Nordstrom Gauge Cock.

Lubricator

SWIFT LUBRICATOR COMPANY

An improved lubricator for steam-driven pumps, engines, hoists, hammers, flue cleaners or internal oiling wherever steam is used has been announced by Swift Lubricator Company, Elmira, New York. It is available in single and double connection styles, and in 1/4, 1/3 and 1 pint, and 1 quart sizes.



Swift Lubricator

The new lubricators have a new fin-type condensing chamber enabling greater condensation capacity and more rapid feed when necessary .Ribs are so constructed as to increase resistance against bursting the chamber through accidental freezing during cold weather. Pyrex glasses are available for pressures up to 150 pounds, and special high pressure Pyrex glasses and Neoprene gaskets are available for pressures to 350 pounds. Regulating valves are packed with a special Garlock solid-ring packing made especially for the

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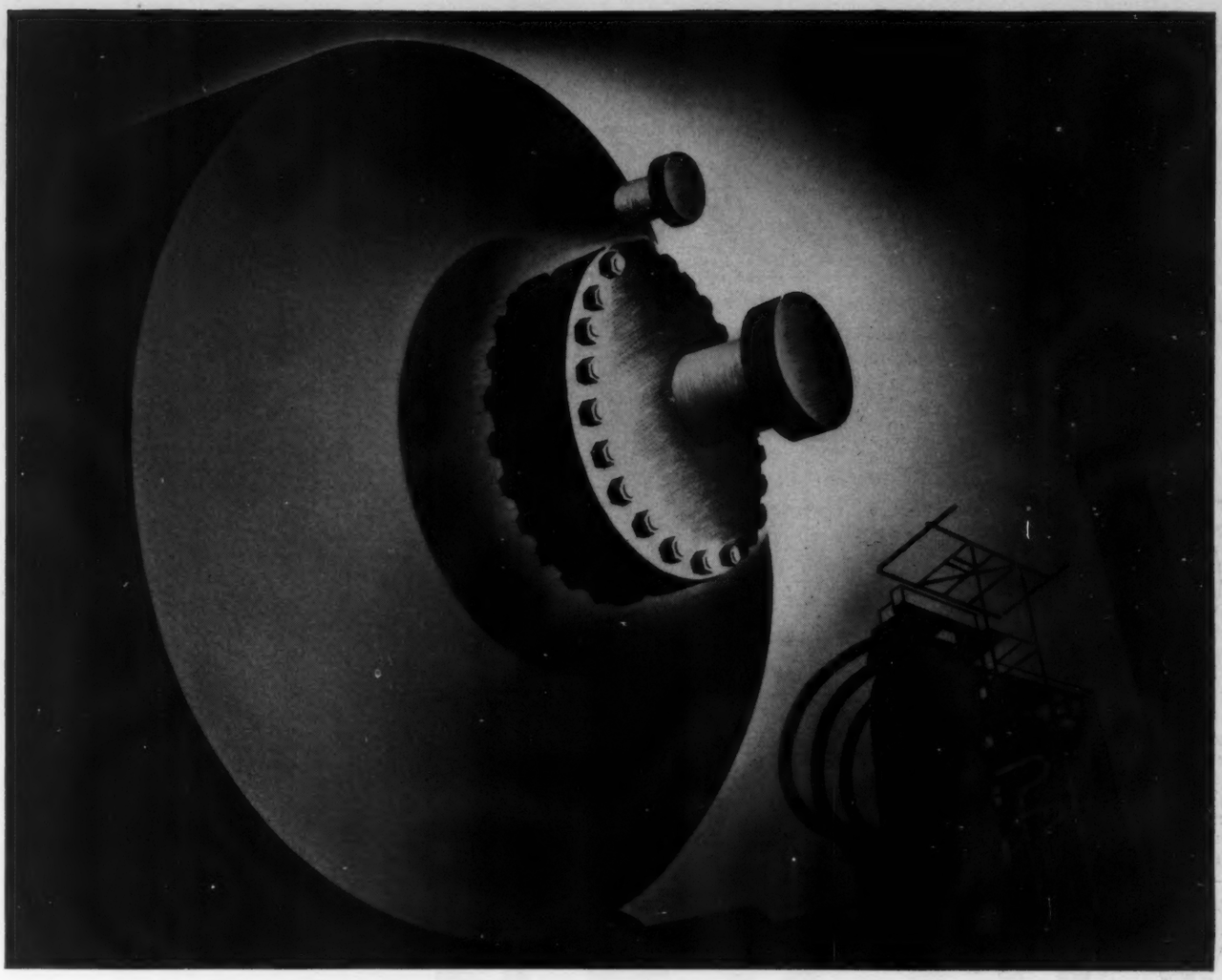

HOLDING WHERE IT'S HOT

What with temperatures ranging up to 1000° F. and high stresses, the bolts used in much oil refinery equipment have no sinecure — and the failure of a single bolt may cause plenty of trouble.

That is why Chromium—Molybdenum (SAE 4140) steel is being more and more widely used for high temperature bolting on reaction chambers, pumps, etc.

This steel meets ASTM Specifications A 193-37 T. At the elevated temperatures encountered it has all the requisite physical properties, including good creep strength.

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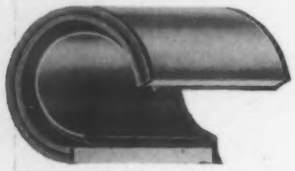
lubricator. Castings are made from a nickel-bronze composition to withstand heavy working pressure. Knurled composition handles have replaced the wooden valve wheels used on the old model, ending possibility of handles drying up from heat of the steam and cracking off. The knurl enables perfect grip and operation even with oily hands.

Improved parts are made to interchange with the company's lubricators now in service.

Packing

TEXAS RUBBER & SPECIALTY CORPORATION

Texas Rubber & Specialty Corporation, Houston, Texas, has announced volume production of the improved Okeh patented self-sealing lip rod packing, the original self-sealing lip packing for this purpose. In the packing there are no metal parts to rust and cause sticking.



Okeh Packing

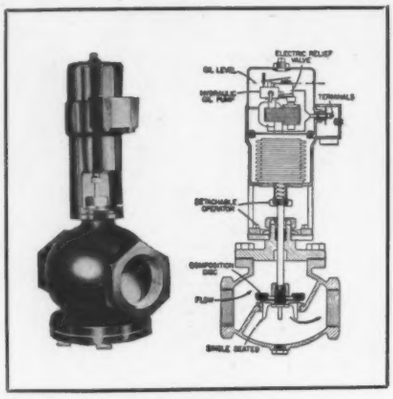
Okeh lip rod packing is a combination of hard outer rubber and soft abrasion-resisting rubber. It permits a seal at both ends of the packing, and the manufacturer explains that it cannot be made up too tightly in the stuffing box.

The lip seals in proportion to the pressure being pumped against it. The unit seals out abrasive fluid and thereby materially lengthens the life of the pump rods.

Hydramotor Valve

GENERAL CONTROLS COMPANY

General Controls Company, Glendale, California, has announced a new hydramotor valve, a hydraulically-operated motor valve for handling air, gas, water, oil, brine or saturated steam. It is described as the culmination of four years of intensive research, engineering and testing in both laboratory and field.



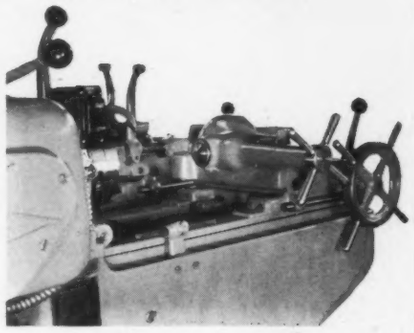
General Hydramotor

The new valve is of the full-ported, single-seated type and affords 100 percent tight shutoff in any position. The electric pilot valve has a simple, two-wire current failure control with current consumption of 60 VA during the opening cycle and 5 VA when open. No gears are used and there is only one internal switch. The entire operator is totally enclosed, sealed in oil, and is drip-proof. There are a minimum number of moving parts, all of which are bathed in oil, and the entire operator is detachable from the valve body.

Carriage Front

LANDIS MACHINE COMPANY

Landis Machine Company, Waynesboro, Pennsylvania, has announced a new type of carriage front which can be used on either its Landmaco or Landis standard threading machines.



Landis Carriage Front

It is provided with a collet holding device of the type usually employed on automatic screw machines. The collet chuck is actuated by a handwheel, located so that it occupies approximately the same position as the handwheel of the standard carriage front. An operator can easily accustom himself to the new type of chuck in a minimum of time.

Separate collets are employed for each diameter of work, and can be interchanged readily.

Centrifugal Pump

WORTHINGTON PUMP & MACHINERY CORPORATION

A new balanced monobloc centrifugal pump, wherein the motor and pump have been engineered as an integral unit of balanced functional design in contrast to merely adapting a motor to a pump, has been announced by Worthington Pump & Machinery Corporation, Harrison, New Jersey.

The new unit is compact, requiring a minimum of floor space, yet is provided with ample room for repacking the stuffing box. A shaft of large diameter, on rigid bearing mountings, maintains concentricity in all rotating parts, thereby increasing packing life. The new drip-proof motor features a directed flow of ventilating air which prevents drawing of moisture into the

Worthington Centrifugal Pump

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Equipment for Refinery at Spokane, Washington, ASME Code Construction throughout 18 Carloads in all.

COMPOSITE CATALOG REFINERY EQUIPMENT PAGE 333

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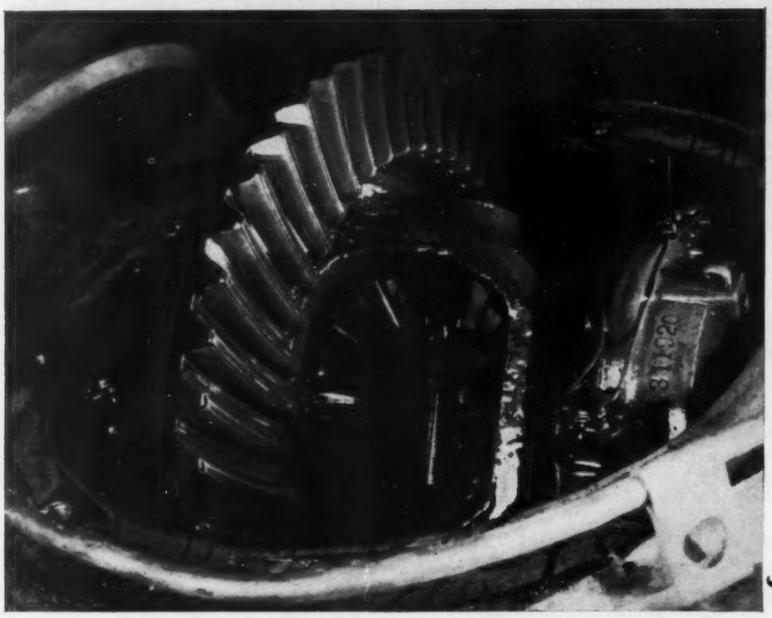
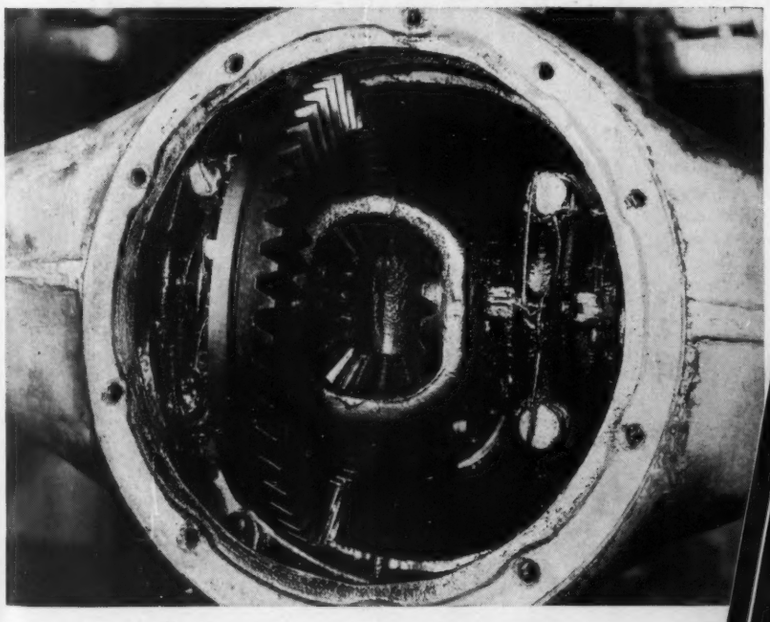
SANTOPOID A, NEW E. P. LUBRICANT BASE, PREVENTS WEAR AND TEAR ON HYPOID GEARS

COMPARATIVE RESULTS OF ROAD TESTS



At finish of 15,000-mile test run (including both city and country driving), an S. A. E. 90 grade differential lubricant containing 10 percent Santopoid A looked like this —clean and free from any trace of sludge. (Unretouched photograph.)



This unretouched photograph shows a hypoid differential after 10,000 miles of operation with an effective but corrosive lubricant. Note accumulation of corrosion sludge.

Over 2,000,000 miles of road tests prove advantages of new addition agent for gear lubricants

An outstanding development in hypoid lubrication is represented in Santopoid A. This new Monsanto product, approved by leading automobile manufacturers, is an all-purpose base for extreme pressure lubricants and is usable in a wide variety of gear lubricants for passenger cars and trucks.

Gear lubricants containing Santopoid A have been demonstrated to be:

1. High in film strength.
2. Non-corrosive and non-wear inducing.
3. Stable, because Santopoid A is miscible in all proportions with oil base.
4. Applicable in all differentials and transmissions.

The photographs at the left show comparative results of road tests. Further details on this test and others are given in Application Data Bulletin No. 117. copy of which will be sent on request. MONSANTO CHEMICAL COMPANY, Petroleum Chemicals Department, St. Louis, U. S. A.

Two other developments in chemicals for the petroleum industry are:

SANTOLENE A: An excellent color stabilizer and gum inhibitor for gasolines.

SANTOLUBES 31 and 36: For the protection of hard alloy bearings against corrosion.

MONSANTO CHEMICALS

SERVING INDUSTRY... WHICH SERVES MANKIND

motor, according to the manufacturer.

The new unit is offered in sizes of from 1 inch to 4 inches, with capacities to 1000 gallons per minute against heads up to 280 feet. It is available in bronze fitted, all-iron and all-bronze construction, horizontal or vertical mountings, with motor of any electrical characteristic.

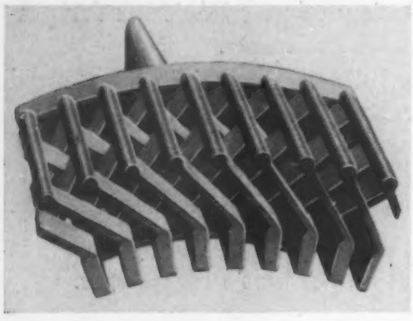
Valv-Amp Rotor

GENERAL ELECTRIC COMPANY

A new-type rotor has been announced by General Electric Company, Schenectady, New York. It is described as offering the advantage of longer life with less maintenance by making possible use of cast-aluminum rotors in the larger sizes of double-squirrel-cage motors for high-starting-torque, low-starting-current service.

Called the Valve-amp rotor, it makes use of a unique shape of rotor slot and a special method of assembling rotor punchings to control the flow of starting current. As a result, without the use of a switch or other moving parts, current is permitted to flow in the outer squirrel-cage when the motor is started, thus producing high-starting torque. When the motor comes up to speed, current is allowed to flow through the entire rotor "winding," resulting in excellent running characteristics, according to the manufacturer.

The Valv-amp development allows the construction of larger cast-rotor motors which inherently combine the advantages of the double-squirrel-cage motor, such as high-starting torque, low-starting current and excellent running characteristics, with advantages of the conventional cast-rotor motor—simplicity of construction, long motor life, little maintenance and permanence of electric characteristics.



G. E. Rotor

Arc Welding Set

GENERAL ELECTRIC COMPANY

General Electric Company, Schenectady, New York, has redesigned its 1500-ampere constant potential arc welding sets for multiple-operator and machine welding into a more compact unit of lighter weight which provides greater convenience of installation. The unit now has control for motor and generator mounted on a base for more convenient operation.

Where a number of operators are supplied from one set, advantage can be taken of the fact that average hand welding is not continuous. This diversity allows the use of smaller capacity in supplying a given connected load.

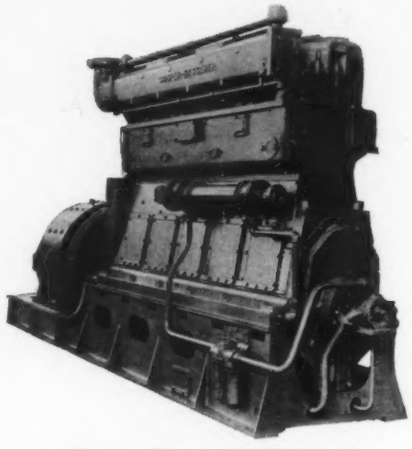
The sets are equipped with standard driving motors for operation on direct current or on a polyphase alternating current at any commercial voltage.

Vertical Diesel Engine

THE COOPER-BESSEMER CORPORATION

A new 4-cycle model, designated Type JS, has been added to the line of vertical Diesel engines of The Cooper-Bessemer Corporation, Mt. Vernon, Ohio.

The base of the engine is divided close to the centerline of the crankshaft, and the cylinder block is bolted to it by steel tie-bolts extending to a point just above the crankcase covers. Separate cylinder liners of the wet type are fitted with oil-proof grommets at their upper and lower ends to seal the water joints. The liners are held down and in place by the cylinder heads and are supported on shoulders



Cooper-Bessemer JS Diesel

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Then packing judgment you will show
For the "O" is a sign
Of the Greene, Tweed line
And that is tops as we all know.

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for steam, air, hot fluids
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for water
PELRO
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CUTNO
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for acids

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By GUSTAV EGLOFF, *Director of Research*, Universal Oil Products Company, Chicago,

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The first volume deals with the paraffin, olefin, acetylene and other aliphatic groups, together with all the data from which the values given are derived. The work is restricted to these four constants chiefly because they are the ones most frequently employed in identifying hydrocarbons, and in industrial engineering. The basic idea underlying this four-volume compilation has been to contribute to our fundamental knowledge of hydrocarbons from the scientific as well as the pragmatic point of view. It will be of inestimable service to all organic chemists, and to many other workers in industries in which hydrocarbon chemistry plays an important part, such as the petroleum, natural and manufactured gas, coal and coke, rubber, plastics, pharmaceutical and dyestuff industries.

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a few inches below the tops of the liners.

The crankshaft is a one-piece steel forging with a diameter of nine inches. Main bearings in the engine are babbitt-lined steel shells of the precision type, with shim adjustment. The main bearing cap is set into the bedplate to hold the bearing firmly in place and provide accurate alignment.

Die-forged steel connecting rods are used, having two-piece crankpin boxes and fitted with fully removable precision bearings with shim adjustment. The piston pin ends of the connecting rods are bolted solid to the piston pins to provide greater bearing surface. Piston pin bearings are two-piece solid bronze shells, which afford a practically full-length bearing.

Undersides of piston crowns are jacketed and oil cooling is provided. This oil cooling of pistons is a new feature of "J" line engines and, according to the manufacturer, goes far toward eliminating wear, warpage and sticking of piston rings, and scuffing of liners; at the same time assuring lower piston temperatures, which in turn, permits higher speeds and greater horsepower output with no danger to piston assemblies. Eight piston rings are used, five of the compression type and three of the oil control, with one of the latter below the piston pin.

A single, quadruple chain, driven by the camshaft, drives the fuel pump and auxiliary drive shaft. The camshaft is located on the operating side of the engine near the top of the cylinder block. The camshaft trough is cast integral with the block and fitted with precision bearings. Short push rods and rocker arms, operated by cams on the camshaft, actuate the main valves. The entire camshaft assembly: shaft, rocker arms, push rods, cams and all connections are fully pressure lubricated, even the valve stems receiving an automatic supply of oil from the forced feed system.

Individual cylinder heads are bolted to the top of the cylinder block. Main valves seat directly in the cylinder heads with special heat-resisting steel inserts being used for the exhaust valves. Outside water jumpers are used for transferring cooling water from cylinders to heads. Cylinder heads are fitted with dust-tight individual covers.

The cooling water header is cast integral with the cylinder block, underneath the air intake header and on the exhaust side of the engine. Cooling water passes from the cylinder heads by means of individual elbow connections to the exhaust manifold jacket. The exhaust valve guide is jacketed and watercooled.

The lubricating system is of the pressure-circulating type. The fuel injection system is the patented Cooper-Bessemer atmospheric-relief type. The high-pressure fuel pump is of the pressure regulating type, whereby the discharge pressure is controlled by regulating the pump suction. Fuel injectors are arranged en bloc, having three or four units grouped in one block, depending upon the number of cylinders. Injectors are mounted on the camshaft housing cover and are gear-driven from the camshaft.

The engine governor is mounted vertically over the chain drive housing and is gear-driven off the end of the camshaft. Air inlet and exhaust outlet connections may be placed at either end of the engine and standard outlet connection is a watercooled elbow.

The gauge board is located in the center of the engine on the operating side and is regularly equipped with fuel oil, lubricating oil and air pressure gauges. Provision is also made for mounting a tachometer when this equipment is specified.

For stationary power and Deisel-electric generating service, the type JS Diesel engine is offered in 5, 6, 7 and 8-cylinder units rated conservatively at 430, 525, 600, and 675 horsepower respectively at 400 revolutions per minute. For direct-reversing marine applications, it is available in 6, 7 and 8 cylinder sizes, of 525, 600 and 675 horsepower at 400 revolutions per minute. Cylinder bore is 13 inches; stroke 16 inches.

WELDING engineers of The International Nickel Company, The Aluminum Company of America, The American Brass Company and Handy & Harmon, Inc., will hold a welding clinic in Houston March 22 and 23.

Latest developments in welding technique as applied to nickel and nickel alloys, brass, copper, and aluminum and aluminum alloys will be demonstrated. All welding methods, including gas and electric, will be included. Particular reference will be made to welding problems as they affect the petroleum and other leading industries of Texas. S. D. Hodgdon, Metal Goods Corporation, announced the clinic to be held at 16 Drennan Street.

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